COPPER SITE-SPECIFIC WATER QUALITY CRITERIA FOR THE PAJARITO PLATEAU: DEMONSTRATION REPORT

Prepared for

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Acronyms

%HA	percent humic acid
AIC	Akaike's Information Criterion
APS	automated pump samplers
AU	Assessment Unit
BIC	Bayesian Information Criterion
BLM	biotic ligand model
BTV	background threshold value
CCC	Criterion Continuous Concentration
CFR	Code of Federal Regulations
CMC	Criterion Maximum Concentration
COC	chain of custody
CWA	Clean Water Act
DOC	dissolved organic carbon
DOE	US Department of Energy
DQA	data quality assessment
DQO	data quality objective
EIM	Environmental Information Management
EPA	US Environmental Protection Agency
ESA	Endangered Species Act
ID	identification
IP	Individual Permit
IPAC	Information for Planning and Consultation
IR	integrated report
LAC	Los Alamos County
LANL	Los Alamos National Laboratory
LOP	level of protection
MLR	multiple linear regression
MSGP	Multi-Sector General Permit
N3B	Newport News Nuclear BWXT Los Alamos
NMAC	New Mexico Administrative Code

NMED	New Mexico Environment Department
NPDES	National Pollutant Discharge Elimination System
ONRW	Outstanding National Resource Water
QA/QC	quality assurance/quality control
SSWQC	site-specific water quality criteria
SWQB	Surface Water Quality Bureau
TAL	target action level
TMDL	total maximum daily load
TOC	total organic carbon
USGS	United States Geological Survey
WER	water-effect ratio
Windward	Windward Environmental LLC
WQC	water quality criteria
WQCC	Water Quality Control Commission
WQS	water quality standards
WWTF	wastewater treatment facility

Executive Summary

This report describes the development of site-specific water quality criteria (SSWQC) for copper in surface waters of the Pajarito Plateau, in accordance with the US Environmental Protection Agency's (EPA's) nationally recommended ambient water quality criteria and New Mexico Water Quality Standards (20.6.4 NMAC) procedures for site-specific criteria.

In 2007, EPA issued revised nationally recommended freshwater aquatic life criteria for copper based upon the biotic ligand model (BLM) (EPA 2007a). EPA recognizes the BLM as best available science for setting copper criteria, because it explicitly considers the effects of multiple water chemistry parameters beyond hardness that affect the bioavailability of copper and its toxicity to aquatic life.

The copper SSWQC were developed using a multiple linear regression (MLR) method that combined water chemistry data from Pajarito Plateau surface waters with output from the copper biotic ligand model (BLM) (EPA 2007a). The MLR-based SSWQC are simple equations that accurately predict acute or chronic copper BLM criteria output using only three water chemistry parameters, making the SSWQC simpler to use than the BLM while maintaining the scientific rigor of the BLM.

The BLM is recognized by the New Mexico Environment Department (NMED) as a more accurate method of assessing copper bioavailability than New Mexico's current hardness-based criteria (NMWQCC 2021). While New Mexico has not yet adopted EPA's ambient water quality criteria statewide because of the data needed to calculate BLM-based copper criteria, it has approved the BLM as a copper SSWQC method (20.6.4.10D(4)(c) NMAC).

Streams on the Pajarito Plateau have been extensively monitored under a variety of EPA and NMED programs over a 15-year period in order to make the Pajarito Plateau a suitable setting for developing BLM-based SSWQC. A site-specific dataset of BLM parameters was developed based on monitoring conducted from 2005 to 2019. The dataset includes a total of 531 discrete samples with sufficient water chemistry parameters to generate BLM-based criteria. Samples were collected from 50 different locations across 9 different watersheds and under a diverse set of hydrologic regimes.

Statistical evaluation of the site-specific dataset demonstrated that pH, dissolved organic carbon (DOC), and hardness account for 98% of the variation in BLM-based criteria for the Pajarito Plateau streams. The influences of other site-specific factors were considered, including hydrologic conditions (i.e., ephemeral, intermittent, or perennial regime), land use (i.e., developed or undeveloped areas), a major forest fire in 2011, and the use of different methods for predicting DOC from total organic carbon (TOC). The statistical evaluation showed that the copper BLM can be simplified, using the MLR method, into the following equations for acute Criterion Maximum Concentration (CMC) and chronic Criterion Continuous Concentration (CCC) :

$$\boldsymbol{CMC = exp(-22.914 + 1.017 \times ln(DOC) + 0.045 \times ln(hardness) + 5.176 \times pH - 0.261 \times pH^2)}$$

$$\boldsymbol{CCC = exp(-23.391 + 1.017 \times ln(DOC) + 0.045 \times ln(hardness) + 5.176 \times pH - 0.261 \times pH^2)}$$

This report demonstrates that these MLR equations accurately estimate BLM criteria over the range of water chemistries and hydrologic regimes observed on the Pajarito Plateau. Therefore, these equations can be adopted as copper SSWQC for surface waters of the Pajarito Plateau to provide criteria that are protective of aquatic life uses in accordance with EPA recommendations (i.e., accurate to the BLM).

1 Introduction

On behalf of Newport News Nuclear BWXT Los Alamos (N3B), Windward Environmental LLC (Windward) has prepared this demonstration report, which describes the development of copper site-specific water quality criteria (SSWQC) for surface waters of the Pajarito Plateau in Los Alamos County (LAC), New Mexico. This report presents and justifies the derivation of a dissolved copper SSWQC in accordance with New Mexico Water Quality Standards (WQS) (20.6.4.10 New Mexico Administrative Code [NMAC]). It also presents the methods, available data, and spatial boundaries for deriving copper SSWQC for surface waters of the Pajarito Plateau.

New Mexico's current aquatic life water quality criteria (WQC) for copper (20.6.4.900 NMAC) are based on the 1996 US Environmental Protection Agency (EPA)-recommended copper criteria (EPA 1996), which were based on an equation that considered only the effect of water hardness on copper bioavailability and toxicity. EPA periodically revises its nationally recommended WQC for aquatic life to reflect current scientific knowledge. In 2007, EPA released updated Clean Water Act (CWA) §304(a) guidance for copper WQC to reflect new knowledge and an improved understanding of the effects of multiple water chemistry parameters on copper toxicity. The EPA (2007a)-recommended copper criteria reflect the "best available science" and significant advancements in scientific understanding of metal speciation, bioavailability, and toxicity.

Per EPA's recommendation, the biotic ligand model (BLM) incorporates these advancements and can be used to generate aquatic life WQC based on local water chemistry. The BLM builds on the old hardness-based criteria by incorporating additional water chemistry parameters that affect copper speciation, bioavailability, and toxicity. The current version of the copper BLM software is available through EPA (https://www.epa.gov/wqc/aquatic-life-criteria-copper).

The statistical model-based approach described in this report for developing copper SSWQC for surface waters of the Pajarito Plateau stems from EPA (2007a) recommendations for using the copper BLM and New Mexico WQS procedures to develop copper SSWQC. The physical and chemical characteristics (i.e., BLM parameters) of Pajarito Plateau surface waters have been rigorously monitored at a variety of locations, so it is a suitable setting to develop copper SSWQC. The proposed SSWQC—multiple linear regression (MLR) equations that accurately predict BLM outputs using a subset of the BLM inputs—are intended for eventual use in all National Pollutant Discharge Elimination System (NPDES) permits and by New Mexico Environment Department (NMED) for CWA §303(d)/305(b) Integrated Assessments.

1.1 Rationale and Methods

Copper is an abundant trace element that occurs naturally in the earth's crust, and an essential micronutrient required by virtually all plants and animals. At elevated concentrations, copper can have adverse effects on some forms of aquatic life, but such effects depend on site-specific chemistry. Both natural and anthropogenic sources introduce copper to Pajarito Plateau surface waters (Los Alamos National Laboratory [LANL] 2013; Windward 2020).

To protect aquatic life uses from copper toxicity, New Mexico's WQS establish the following state-wide dissolved copper criteria based on EPA's outdated 1996 ambient water quality criteria document (EPA 1996):

$$\textbf{Acute criterion } (\mu g/L) = \exp(0.9422 \times \ln(\text{hardness}) - 1.700) \times 0.96$$

$$\textbf{Chronic criterion } (\mu g/L) = \exp(0.8545 \times \ln(\text{hardness}) - 1.702) \times 0.96$$

As described by EPA (2018c), these hardness-based copper criteria were developed from an empirical relationship between toxicity and water hardness. Their development did not explicitly consider the effects of other water chemistry parameters that markedly affect copper bioavailability and toxicity.

In February 2007, EPA published *Aquatic Life Ambient Freshwater Quality Criteria – Copper* to address water chemistry parameters beyond hardness, and to reflect the latest scientific knowledge on copper bioavailability and toxicity (EPA 2007a). The criteria 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 scientific information, supplementing EPA's previously published recommendation 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 concentration of copper that will be protective of aquatic life." By using the BLM to develop MLRs, this demonstration report relies on the most recent available scientific information and EPA's current recommendations to develop copper SSWQC.

EPA's regulation at 40 Code of Federal Regulations (CFR) 131.11(b)(1)(ii) provides that states and tribes may adopt WQC that have been modified to reflect site-specific conditions. New Mexico WQS describe conditions under which SSWQC may be developed, including "physical or chemical characteristics at a site such as pH or hardness alter the biological availability and/or toxicity of the chemical" (20.6.4.10.D(1) NMAC). Consistent with EPA regulations, New Mexico WQS require a scientifically defensible method to derive SSWQC. The WQCC explicitly recognizes "the biotic ligand model as described in aquatic life ambient freshwater quality criteria – copper" (EPA 2007a) as one such scientifically defensible method to derive SSWQC (20.6.4.10.D(4) NMAC).

In addition, 40 CFR 131.20(a) requires that States adopt EPA Section 304(a) criteria or provide an explanation if not adopted when the results of the Triennial Review are submitted consistent with CWA section 303(c). As part of New Mexico's 2020 Triennial Review, EPA recommended that New Mexico update its aquatic life criteria for copper to reflect the latest science contained in the 304(a) copper criteria (EPA 2020). NMED stated in direct testimony that the BLM provides a more accurate assessment of copper bioavailability than New Mexico's hardness-based criteria calculation, but noted that it requires multiple water quality parameters (some of which are not commonly available) as a potential limitation of the copper BLM, and therefore, recommended that the WQCC not adopt the criteria state-wide. The limitation described in the 2020 Triennial Review is not an issue for the current proposal because BLM parameters have been sampled in Pajarito Plateau surface waters since 2005. Furthermore, the proposed copper SSWQC equations use only a subset of the BLM input parameters.

The EPA (2007a) copper BLM explicitly and quantitatively accounts for how individual water quality parameters affect the bioavailability and toxicity of copper to aquatic organisms. The BLM software relies on 12 water chemistry parameters as inputs to generate BLM-based WQC, but most parameters have little or no effect on the speciation, bioavailability, and toxicity of copper and, thus, on the magnitude of any resulting BLM-based WQC.[1]

To provide a more streamlined and transparent approach for adopting and implementing copper SSWQC for the Pajarito Plateau, BLM-based WQC were simplified into three-parameter acute and chronic equations using an MLR method. This approach is consistent with EPA's approach for setting WQC for other chemicals,[2] as well as with approaches described in the scientific literature for developing copper WQC (e.g., Brix et al. 2017) and EPA-approved approaches for simplifying the copper BLM into an MLR equation for SSWQC (EPA 2016a).

The proposed copper SSWQC equations were developed based on statistical analyses of BLM parameters monitored in Pajarito Plateau streams from 2005 to 2019. Three parameters (pH, dissolved organic carbon [DOC], and hardness) were found to have a significant impact on BLM-based criteria for the site-specific dataset. The SSWQC equations build upon New Mexico's current hardness-based equations to incorporate the combined effects of pH, hardness, and DOC. The evaluations presented in this report demonstrate how the proposed SSWQC equations accurately

[1] The BLM can also be used to evaluate the site-specific speciation, bioavailability, and toxicity of copper and several other metals. The sensitivity of the BLM's output to a given water chemistry parameter varies among different metals. When the BLM is being used to develop WQC for a single metal—in this case, copper—the model can be simplified to include only the sensitive parameters for that metal as model variables.

[2] For example, EPA-recommended aquatic life criteria for aluminum and ammonia are based on MLR equations that use multiple water quality parameters to generate criteria (EPA 2013, 2018b).

estimate EPA (2007a) BLM-based copper criteria over the range of water chemistries and hydrologic regimes of the Pajarito Plateau.

1.2 REPORT CONTENTS

The remaining report is organized into the following sections:

- Regulatory background for establishing SSWQC (Section 2)
- Background on the physical setting, New Mexico WQS, permitted discharges, and monitoring programs (Section 3)
- Overview of scientific methods and regulatory processes for deriving SSWQC (Section 4)
- Summary of available surface water data and methods for deriving copper SSWQC (Section 5)
- Recommended copper SSWQC for surface waters of the Pajarito Plateau (Section 6)
- References cited (Section 7)

Additionally, there are four appendices to this report:

- Appendix A is a table of the data used to develop SSWQC.
- Appendix B provides additional details on the SSWQC development methods and results.
- Appendix C is the Public Involvement Plan (also see Section 2.1.5).
- Appendix D is an evaluation of threatened and endangered species (also see Section 2.5).

2 Regulatory Background

This section provides the regulatory background and framework for developing SSWQC in accordance with EPA guidance and New Mexico's WQS.

2.1 Regulatory Framework for Developing SSWQC

EPA's regulation at 40 CFR 131.11(b)(1)(ii) provides that states and tribes may adopt WQC that are "modified to reflect site-specific conditions." As with all criteria, SSWQC must be based on sound scientific rationale, protect designated uses, and are subject to EPA review and approval or disapproval under §303(c) of the CWA (EPA 2007a).

New Mexico's WQS (20.6.4.10.D NMAC) specify the following requirements for adopting SSWQC for New Mexico surface waters:

- Relevant site-specific conditions for developing SSWQC
- Protectiveness of SSWQC to designated uses
- Scientific methods for deriving SSWQC
- Petition and stakeholder/public review process for adopting SSWQC

Each factor is discussed in the following sections.

2.1.1 Relevant conditions for developing SSWQC

In accordance with New Mexico's WQS (20.6.4.10.D.1 NMAC), SSWQC may be adopted based on relevant site-specific conditions, such as:

- Actual species at a site are more or less sensitive than those used in the national criteria dataset.
- Physical or chemical characteristics at a site, such as pH or hardness, alter the biological availability and/or toxicity of a chemical.
- Physical, biological, or chemical factors alter the bioaccumulation potential of a chemical.
- The concentration resulting from natural background exceeds numeric criteria for aquatic life, wildlife habitat, or other uses if consistent with Subsection E of 20.6.4.10 NMAC.
- Other factors or combination of factors, upon review by Water Quality Control Commission (WQCC), may warrant modification of the default criteria, subject to EPA review and approval.

The rationale for the copper SSWQC described in this report is that water chemistry parameters beyond hardness alter the bioavailability and toxicity of copper to aquatic organisms (EPA 2007a). EPA recommends using the copper BLM to establish copper criteria, as the BLM incorporates the effects of multiple water chemistry parameters and reflects the best available scientific information.

NMED recognizes that the BLM represents the best available science for setting copper WQC (NMWQCC 2021). It recommended that within New Mexico the BLM be adopted on a site-specific basis. Because LANL has analyzed BLM parameters for a large number of surface water samples from the Pajarito Plateau (Appendices A and B), site-specific adoption of the BLM for waters of the Pajarito Plateau is appropriate and consistent with the New Mexico WQS. The proposed SSWQC are based on statistical evaluation and modeling demonstrating that pH, DOC, and hardness have a significant effect on accurately generating BLM-based copper criteria, consistent with findings that others have reported (EPA 2007a). Additional discussion of Pajarito Plateau-specific water chemistry conditions and how they influence copper criteria is provided in Section 5 (e.g., Sections 5.1, 5.3, and 5.4).

2.1.2 Protectiveness of SSWQC

In accordance with 20.6.4.10.D.2 NMAC, "site-specific criteria must fully protect the designated use to which they apply." The copper SSWQC described in this report are based on EPA (2007a) criteria for protection of aquatic life uses and will fully protect aquatic life uses on the Pajarito Plateau to the same extent as the EPA (2007a) criteria.

Relative to hardness-based copper WQC for aquatic life, EPA (2007a) reports:

> 'Stringency' likely varies depending on the specific water chemistry of the site. The 1986 hardness-based equation and resulting copper criteria reflected the effects of water chemistry factors such as hardness (and any of the other factors that were correlated with hardness, chiefly pH and alkalinity). However, the hardness based criteria, unadjusted with the WER [water effect ratio], did not explicitly consider the effects of DOC and pH, two of the more important parameters affecting copper toxicity. The application resulted in copper criteria that were potentially under-protective (i.e., not stringent enough) at low pH and potentially over-protective (i.e., too stringent) at higher DOC levels.
>
> By contrast, the BLM-based recommended criterion should more accurately yield the level of protection intended to protect and maintain aquatic life uses. By using the latest science currently available, application of the BLM-derived copper criteria should be neither under-protective nor over-protective for protection and maintenance of aquatic life uses affected by copper.

BLM-based WQC may be higher or lower than hardness-based WQC, depending on water chemistry. When the BLM-based WQC are lower, they are sometimes mistakenly referred to as "more stringent" (and vice-versa). Rather, changes in the

BLM-based WQC reflect changes in water chemistry and copper bioavailability, not changes in the stringency (i.e., level of protection [LOP]). As described by EPA (2021), BLM-based criteria will in some cases be higher and in other cases be lower than hardness-based criteria. "Although there is not a single water quality criteria value to use for comparison purposes, the BLM-based water quality criteria for copper provides an improved framework for evaluating a 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" (EPA 2021).

Thus, the copper SSWQC described in this report will fully protect aquatic life uses on the Pajarito Plateau in accordance with EPA recommendations.

As part of this evaluation, Rio Grande water chemistry data from the National Water Quality Monitoring Council's Water Quality Portal website (National Water Quality Monitoring Council 2019) were considered to ensure that the SSWQC would not affect waters downstream of the Pajarito Plateau. The Rio Grande has not been listed as impaired due to copper in past 303(d) evaluations presented in New Mexico's integrated reports (IRs) (e.g., NMED 2018), neither above nor below confluences with Pajarito Plateau tributaries. Using New Mexico's current hardness-based copper criteria, the copper BLM, and the simplified SSWQC, copper concentrations in the Rio Grande were found not to exceed any criteria (more detail in Section 5.6). Therefore, a change on the Pajarito Plateau from the hardness-based criterion to the SSWQC would not adversely impact the Rio Grande downstream of its confluence with plateau tributaries.

No changes are proposed to existing or designated aquatic life uses or for non-aquatic life criteria such as irrigation, livestock watering, wildlife habitat, primary or secondary human contact, or drinking water. In addition, the proposed SSWQC change is not associated with new discharges of copper nor changes to existing discharges of copper.

2.1.3 Scientific methods for SSWQC

Under 20.6.4.10.D.4 NMAC, "a derivation of site-specific criteria shall rely on a scientifically defensible method, such as one of the following:

(a) the recalculation procedure, the water-effect ratio procedure metals procedure or the resident species procedure as described in the water quality standards handbook (EPA-823-B-94-005a, 2nd edition, August 1994)

(b) the streamlined WER procedure for discharges of copper (EPA-822-R-01-005, March 2001)

(c) the biotic ligand model as described in aquatic life ambient freshwater quality criteria – copper (EPA-822R-07-001, February 2007)

(d) the methodology for deriving ambient water quality criteria for the protection of human health (EPA-822-B-00-004, October 2000) and associated technical support documents; or

(e) a determination of the natural background of the water body as described in Subsection E of 20.6.4.10 NMAC."

In accordance with current EPA recommendations, the copper SSWQC described in this report were developed using the copper BLM and site-specific water chemistry to reflect copper bioavailability under varying water chemistry conditions on the Pajarito Plateau.

Prior to its publication of the 2007 copper criteria document, EPA recommended the water-effect ratio (WER) procedure to adjust copper criteria "to address more completely the modifying effects of water quality than the hardness regressions achieve" (EPA 2007a). EPA's Science Advisory Board found that compared to the WER procedure, the BLM can significantly improve predictions of copper toxicity to aquatic life across an expanded range of water chemistry parameters (EPA 2000).

As described in Section 5 of this report, EPA's BLM method was streamlined to substitute simple MLR equations for acute and chronic SSWQC[3] from a relatively complex software-based model. MLR is also a scientifically defensible method for generating WQC as a function of multiple water chemistry parameters (Section 4.3). Given the high degree of agreement between the MLR-predicted and BLM-based WQC (Section 5.4.2) and the scientific rigor associated with the BLM, the copper SSWQC presented in this report meet the 20.6.4.10.D.4 NMAC requirement that SSWQC be derived based on a scientifically defensible method.

2.1.4 Copper SSWQC petition

In accordance with WQCC regulations (20.1.6.200.A and 20.6.4.10.D(3) NMAC), any person may petition the WQCC to adopt SSWQC. WQCC regulations require that a petition for the adoption of SSWQC "be in writing and shall include a statement of the reasons for the regulatory change. The petition shall cite the relevant statutes that authorize the commission to adopt the proposed rules and shall estimate the time that will be needed to conduct the hearing. A copy of the entire rule, including the proposed regulatory change, indicating any language proposed to be added or deleted, shall be attached to the petition. The entire rule and its proposed changes shall be submitted to the commission in redline fashion, and shall include line numbers" (20.1.6.200.B NMAC). In addition, the regulations at 20.6.4.10.D(3) NMAC require that a petition do the following:

[3] The proposed SSWQC equations are analogous to the hardness-based equations used in the statewide WQS for copper, but the proposed SSWQC equations are more accurate because they include DOC and pH in addition to hardness.

(a) Identify the specific waters to which the SSWQC would apply.

(b) Explain the rationale for proposing the SSWQC.

(c) Describe the methods used to notify and solicit input from potential stakeholders and from the general public in the affected area, and present and respond to the public input received.

(d) Present and justify the derivation of the proposed SSWQC.

LANL will develop a draft petition for copper SSWQC based on: 1) conclusions and recommendations presented herein, 2) NMED and EPA comments on this report, and 3) input from other potential stakeholders, tribes, and the general public. The petition will include all information required under 20.1.6.200 and 20.6.4.10 NMAC for WQCC review.

2.1.5 Public involvement plan

A public involvement plan was developed to outline the general process and schedule for public, tribal, and stakeholder involvement in the development of the copper SSWQC. The complete plan is provided in Appendix C. Specific objectives of the plan are as follows:

- Identify potential stakeholders, tribes, and general public members who may be affected by the proposed copper SSWQC.
- Establish a process to present the proposed copper SSWQC to stakeholders, tribes, and the general public.
- Establish a process to receive and respond to input from stakeholders, tribes, and the general public on the proposed copper SSWQC.
- Develop a draft schedule for stakeholder, tribal, and general public engagement.

2.2 ANTIDEGRADATION

New Mexico's antidegradation policy (20.6.4.8 NMAC) applies to all surface waters of the state and to all activities with the potential to adversely affect water quality or existing or designated uses. Such activities include:

- Any proposed new or increased point source or nonpoint source discharge of pollutants that would lower water quality or affect the existing or designated uses
- Any proposed increase in pollutant loadings to a waterbody when the proposal is associated with existing activities
- Any increase in flow alteration over an existing alteration
- Any hydrologic modifications, such as dam construction and water withdrawals (NMED 2020a)

This petition does not propose new activities that could impact water quality or existing or designated uses on the Pajarito Plateau. Instead, it proposes updated copper WQC intended to more accurately achieve the level of protection for aquatic life stipulated by EPA guidance (Section 2.1.2). Therefore, an antidegradation review is not required for the proposed SSWQC.

If the proposed copper SSWQC are adopted by the WQCC into New Mexico's WQS, the SSWQC would establish the "level of water quality necessary to protect existing or designated uses" for any future antidegradation review related to any new proposed activity, as defined under New Mexico's antidegradation policy and in accordance with EPA recommendations for the protection of aquatic life uses (Section 2.1.2).

2.3 New Mexico WQS for Pajarito Plateau Surface Waters

Most water bodies on the Pajarito Plateau are classified in New Mexico WQS as ephemeral or intermittent waters (20.6.4.128 NMAC), which are designated as providing limited aquatic life use. According to NMAC, these water bodies are subject to acute criteria only. Only a few water bodies in the area are classified as perennial (20.6.4.121 and 20.6.4.126 NMAC), which are subject to both acute and chronic aquatic life criteria (i.e., Upper Sandia Canyon associated with wastewater treatment plant discharges; isolated segments of Cañon de Valle and Pajarito Canyon associated with local springs; and El Rito de los Frijoles in Bandelier National Monument). Unclassified surface waters (20.6.4.98 NMAC) are designated as providing a marginal warmwater aquatic life use, to which both acute and chronic aquatic life criteria apply. As discussed in Section 5, the proposed copper SSWQC include both acute and chronic criteria equations, so they can be applied as appropriate in accordance with NMAC surface water classifications.

NMED has assigned Assessment Units (AUs) to 50 surface water segments across the Pajarito Plateau, many of which are located within the Laboratory or receive discharges regulated by the Individual Permit (IP), the Multi-Sector General Permits (MSGP), the LANL industrial discharges, or the LAC wastewater treatment facility (WWTF) permit. New Mexico's most recent CWA §303(d)/305(b) IR for the 2020–2022 assessment cycle identifies multiple AUs impaired for aquatic life uses due to exceedances of NMED's hardness-based copper WQC, along with other causes (NMED 2020b). The IR impairment category provided for copper in these surface waters is 5/5B, defined as "impaired for one or more designated or existing uses and a review of the water quality standard will be conducted" (NMED 2018). The assessment rationale for the 2020 to 2022 IR explains that "[s]pecific impairments are noted as IR Cat 5B to acknowledge LANL's ongoing discussions and research regarding applicable water quality standards on the Pajarito Plateau for these parameters." The copper SSWQC described herein, being based on the best available science and current EPA recommendations, should provide more appropriate copper criteria for NMED's CWA §303(d)/305(b) assessments and other site assessments conducted by LANL.

2.4 NPDES Discharges

The NPDES permit regulates four principal types of discharges to Pajarito Plateau waters:

- Stormwater discharges associated with legacy contamination and industrial activities are regulated under the LANL's NPDES Storm Water IP (No. NM0030759).
- Stormwater discharges associated with current industrial activities are regulated under EPA NPDES MSGPs (Nos. NMR050011, NMR050012, and NMR050013).
- Industrial and sanitary wastewater and cooling water discharged from 11 outfalls are regulated under NPDES Permit No. NM0028355.
- Municipal sanitary wastewater discharged to Lower Pueblo Canyon by the LAC WWTF is regulated under NPDES Permit No. NM0020141.

These NPDES permits generally require water quality monitoring and certain actions based on concentrations of copper and other parameters. Current IP target action levels (TALs), MSGP benchmarks, and water quality-based effluent limits for copper applicable to Laboratory NPDES wastewater permits are based on New Mexico's hardness-based dissolved copper criteria (20.6.4.900 NMAC). In its 2019 draft IP Fact Sheet (EPA 2019), EPA suggested that BLM-based values may be considered for effluent benchmarks if BLM-based copper SSWQC are adopted into New Mexico WQS, and if NMED and N3B reach mutually agreeable BLM values through the annual sampling implementation plan. The copper SSWQC presented in this report are intended for eventual use in all NPDES permits and by NMED for CWA §303(d)/305(b) Integrated Assessments.

2.5 Threatened and Endangered Species

Possible effects of copper SSWQC on threatened and endangered species under the federal Endangered Species Act (ESA) were considered as part of this analysis. The Information for Planning and Consultation (IPAC) tool from the US Fish and Wildlife Service's Environmental Conservation Online System website (USFWS 2018) was used to identify listed species potentially present on the Pajarito Plateau and in downstream waters of the Rio Grande. The proposed scope for the SSWQC includes all watersheds from Guaje Canyon in the north to El Rito de Frijoles in the south, as well as from the headwaters of each canyon to the west and their confluences with the Rio Grande to the east. The following species were determined by the IPAC tool to be potentially present on the Pajarito Plateau or in Rio Grande waters (within a reasonable distance downstream of its confluence with Pajarito Plateau streams)[4]:

- New Mexico jumping mouse (*Zapus hudsonius luteus*)
- Mexican spotted owl (*Strix occidentalis lucida*)
- Southwestern willow flycatcher (*Empidonax traillii extimus*)
- Yellow-billed cuckoo (*Coccyzus americanus*)
- Jemez Mountains salamander (*Plethodon neomexicanus*)
- Rio Grande cutthroat trout (*Oncorhynchus clarkii virginalis*)
- Rio Grande silvery minnow (*Hybognathus amarus*)

Critical habitat for Mexican spotted owl and Jemez Mountains salamander would fall within the area potentially affected by the SSWQC (Map 3-1), and Rio Grande silvery minnow critical habitat is downstream of these waters. Each species is briefly evaluated and discussed in Appendix D. Based on these evaluations, it is not expected that implementation of the proposed SSWQC would adversely affect ESA-listed species (directly or indirectly) or their critical habitats.

In general, the species listed above are terrestrial and feed on terrestrial prey (Appendix D), suggesting that exposures to dissolved copper in Pajarito Plateau watersheds should be infrequent. Moreover, the copper BLM (and, by extension, the proposed SSWQC) represents criterion levels intended to be protective of sensitive aquatic species, including salmonids and cyprinids like the Rio Grande cutthroat trout and silvery minnow. It also protects potential prey items of these fish and other species.

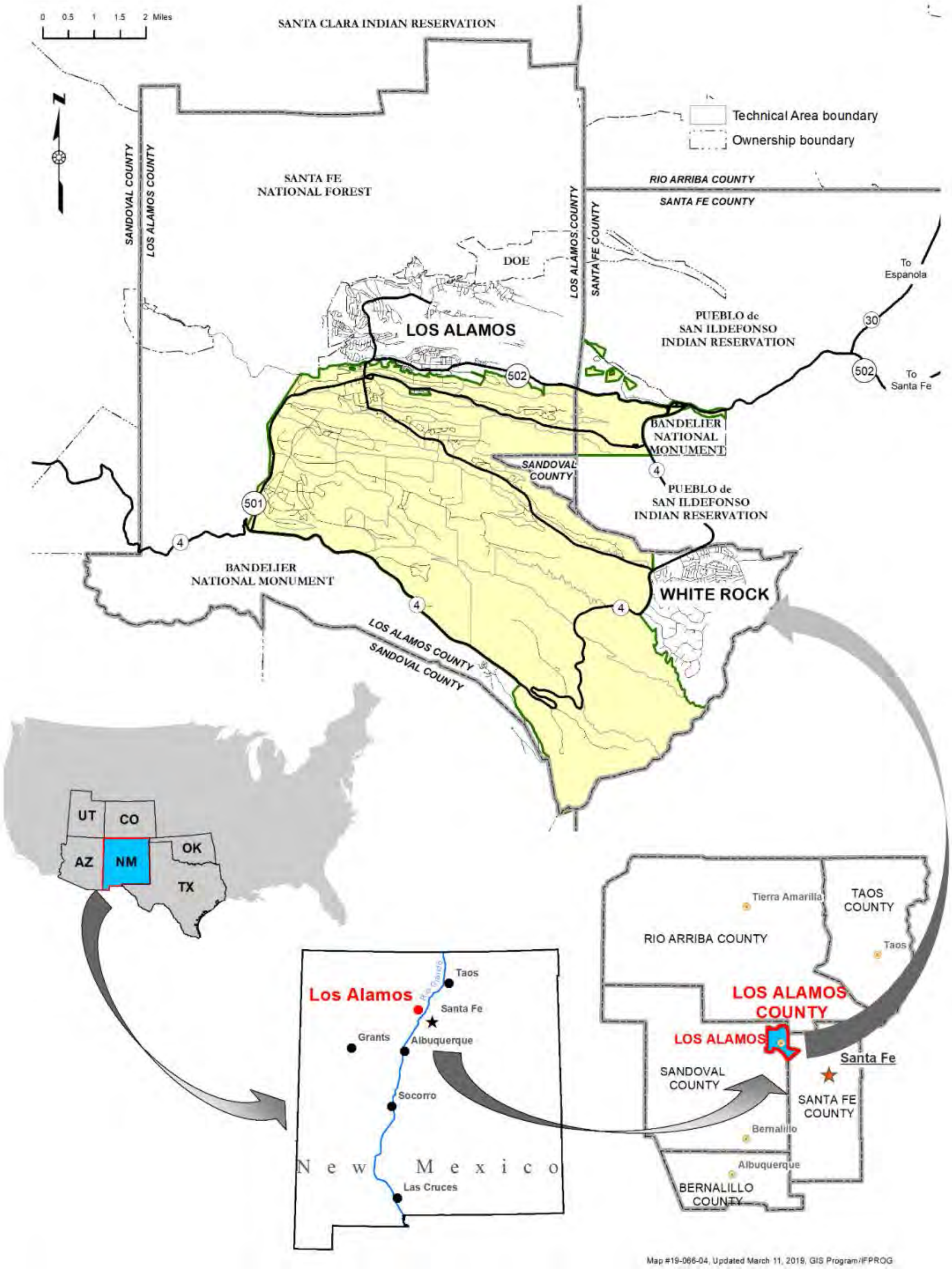
[4] A polygon was drawn using IPAC that included the Pajarito Plateau watersheds plus a 2 mile (approximate) buffer around the plateau (all watersheds). This captured the Rio Grande below the confluence with Pajarito Plateau watersheds.

3 Site Background

The following sections provide general background information on the physical setting, New Mexico's WQS, permitted discharges, and surface water monitoring programs for the Pajarito Plateau.

3.1 Geographic Setting

The Laboratory occupies approximately 36 square miles of US Department of Energy (DOE) lands in LAC in north-central New Mexico, approximately 60 miles north-northeast of Albuquerque and 25 miles northwest of Santa Fe (Figure 3-1). The general region encompassing the Laboratory, towns of Los Alamos and White Rock, Bandelier National Monument, San Ildefonso Pueblo lands, western slopes of the Jemez Mountains, and other surrounding areas is known, geographically, as the Pajarito Plateau. Lands north, west, and south of the Laboratory are largely undeveloped areas held by the Santa Fe National Forest, US Bureau of Land Management, Bandelier National Monument, and LAC (LANL 2013). The communities closest to the Laboratory are the towns of Los Alamos, located just to the north of the main Laboratory complex, and White Rock, located a few miles to the east-southeast.



Source: Hansen et al. (2020)

Figure 3-1. Geographic setting for LANL BLM dataset

3.2 GEOLOGIC SETTING

The Laboratory is situated on fingerlike mesas capped mostly by Bandelier Tuff. The Bandelier Tuff consists of ash fall, pumice, and rhyolite tuff that vary from 1,000 feet thick on the western side of the plateau to about 260 ft thick eastward above the Rio Grande (Broxton and Eller 1995). The mesa tops slope from elevations of approximately 7,800 feet on the flanks of the Jemez Mountains to about 6,200 feet at the mesas' eastern terminus above the Rio Grande Canyon. Natural background copper concentrations in Bandelier Tuff range from 0.25 to 6.2 mg/kg with a median of 0.665 mg/kg (Ryti et al. 1998).

Background copper concentrations in Pajarito Plateau surface waters were recently characterized by Windward (2020). Based on surface water samples collected by LANL between 2015 and 2018, Windward estimated that background dissolved copper concentrations draining from undeveloped landscapes (i.e., excluding the influence of urban runoff) are fairly low (≤ 5.6 µg/L).

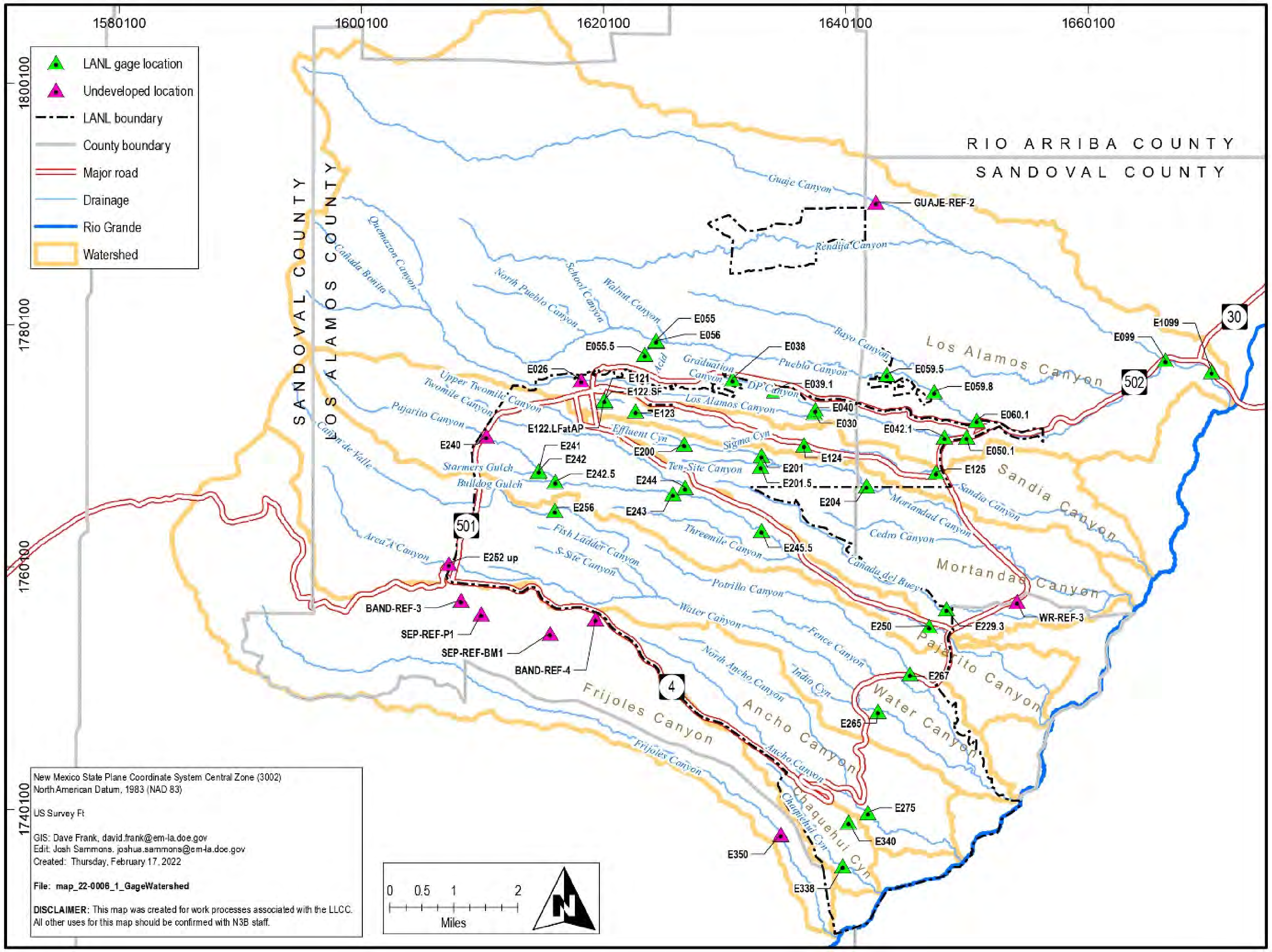
3.3 HYDROLOGIC SETTING

The Laboratory lies within a segment of the upper Rio Grande Basin denoted by the US Geological Survey eight-digit hydrologic unit code 13020101. The upper Rio Grande Basin is a large watershed (approximately 7,500 square miles) that generally flows from north to south. The New Mexico portion of the basin falls within seven counties: Rio Arriba, Taos, Santa Fe, Los Alamos, Sandoval, Mora, and San Miguel.

Surface water runs off the adjacent Jemez Mountains and Pajarito Plateau through steep and narrow canyons, flowing primarily southeast to the Rio Grande; however, surface water flows rarely reach the Rio Grande due to the limited flow durations and infiltration in canyon reaches upgradient of the Rio Grande (N3B 2020; Hansen et al. 2020). Most drainages on the Pajarito Plateau are currently classified as ephemeral or intermittent, because flow only occurs for limited periods in response to rainfall or snowmelt. Summer monsoonal thunderstorms are the sole contributors to flow in the many ephemeral waters, which otherwise remain dry for most of the year. A few canyons contain relatively short segments of intermittent and/or perennial flow attributable to springs, snowmelt, and industrial/municipal effluent discharges. Flows either represent stormflow (e.g., in response to precipitation events) or baseflow conditions, with baseflow generally being limited to perennial reaches and stormflow dominating other reaches.[5]

[5] For the purpose of this discussion, "baseflow" includes both natural baseflow and effluent. For example, "baseflow" in Upper Sandia Canyon is effluent dominated or effluent dependent.

The Laboratory encompasses seven major watersheds: Los Alamos, Sandia, Mortandad, Pajarito, Water/Cañon de Valle, Ancho, and Chaquehui Canyons. Many tributaries to these canyons are identified within the Laboratory as smaller sub-watersheds with other names. Additional sub-watersheds outside of the Laboratory include the 20.6.4.98 NMAC waters to the north (e.g., Pueblo, Bayo, Guaje, and Rendija Canyons and their tributaries). Frijoles Canyon, located to the south of the Laboratory, is another major watershed on the Pajarito Plateau. A depiction of the Pajarito Plateau, related water bodies, surface water sampling locations, the Laboratory, the towns of Los Alamos and White Rock, and Pueblo and County boundaries is presented in Map 3-1.



Map 3-1. Sampling locations for BLM data on the Pajarito Plateau

3.4 SAMPLING AND ANALYSIS PROGRAMS

This section provides a brief description of the sampling programs under which surface water quality data used to develop the copper SSWQC were collected. All samples included in the BLM dataset (Appendix A) were collected under sampling and analysis programs, validated, and reported previously to NMED under the various sampling programs described below.

3.4.1 Sampling

LANL conducts various surface water quality monitoring programs at many locations on the Pajarito Plateau. The programs are typically related to permit compliance monitoring and monitoring required under the NMED (2016) Compliance Order on Consent, although periodic investigative studies are also conducted to better understand and manage surface waters on the plateau. LANL is not obligated to sample and analyze for BLM parameters but has generally done so in response to EPA recommendations for developing aquatic life criteria for metals (EPA 2007a).[6]

Although surface water samples are sometimes collected as discrete grabs, most samples collected by LANL to date have been through its network of automated pump samplers (APS) located at various streamflow gaging stations. These devices are triggered when there is sufficient streamflow, often generated by a storm (typically during the summer monsoon season).[7] When there is sufficient flow, an internal pump initiates, drawing surface water into a series of sample bottles that remain in the APS until collected by a field technician (typically within 24 to 48 hours). Regardless of the sampling method, all samples are collected in pre-cleaned bottles to prevent contamination. The technician delivers the bottles to a sample processing facility, where each bottle is refrigerated, filtered, and/or chemically preserved as appropriate for the target analytes. Next, the sample is transferred to the sample management office and finally to LANL's contract laboratory for chemical analysis. This process is carried out by trained and qualified personnel under approved standard operating procedures (see Section 3.4.2). Quality control/quality assurance (QA/QC) measures are maintained during the sampling and transport processes, including the collection of field duplicates and maintenance of field blanks. Chain of custody (COC) forms are used to track the collection and delivery of samples to laboratories. Appendix A

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[6] BLM parameters that have been consistently analyzed by LANL include pH, DOC, calcium, magnesium, alkalinity, potassium, sulfate, and chloride. Temperature, %HA, and sulfide values are generally not determined and have been assumed, as discussed in Section 4.2.

[7] APS are generally in operation during the summer, when storm events result in sufficient flow; outside of this time period, samples cannot be collected consistently, so APS are not always in operation. Therefore, multi-seasonal datasets cannot be established for many streams on the Pajarito Plateau. Multi-seasonal data are available, however, for perennial reaches such as Upper Sandia Canyon (Appendix A).

provides COC numbers associated with each sampling event, as well as the sample collection and retrieval dates/times and laboratory receipt and analysis dates/times.

Due to the ephemeral/intermittent nature of many of the drainages, most surface water samples are collected during the late spring to early fall, during the monsoon season. However, samples are also collected during other parts of the year in perennial stream segments. Figure 3-2 summarizes the distribution of sampling over the year by month and season for the samples included in the BLM dataset (Appendix A).[8]

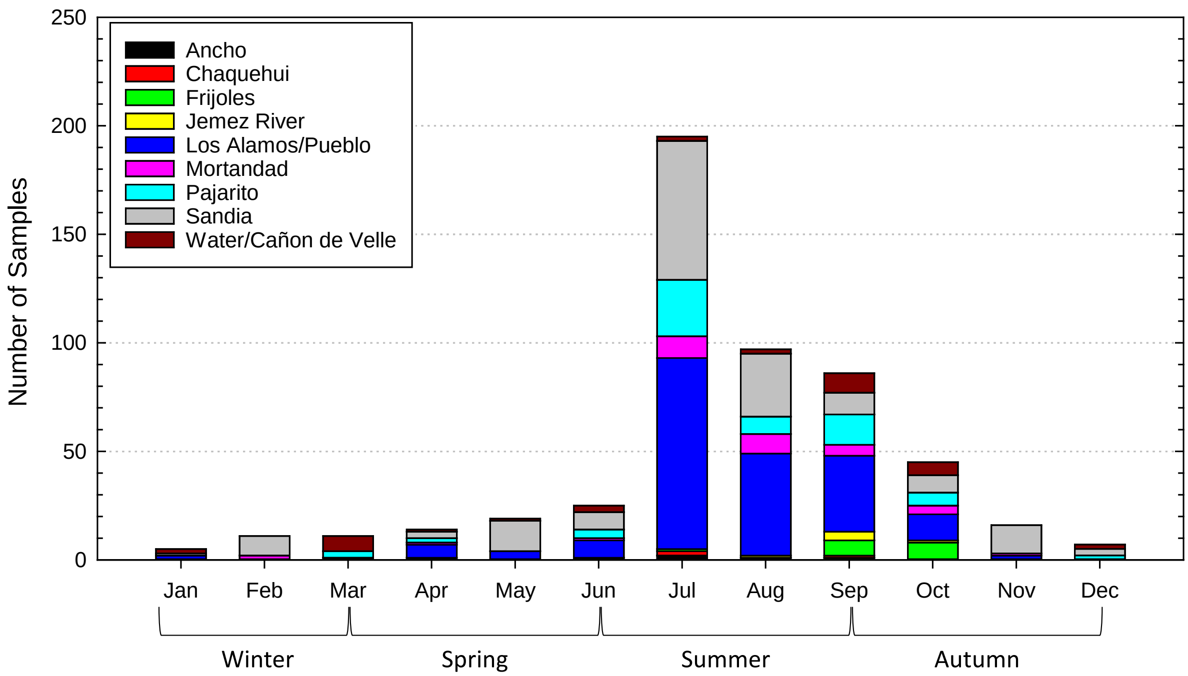

Figure 3-2. Distribution of BLM samples by watershed and season, 2005 to 2019

All BLM data from 2005 to 2019 were collected as part of five general programs in accordance with the laboratory and data validation procedures described in Section 3.4.2:

- Annual Site Environmental Report Program
- Los Alamos/Pueblo Canyon Sediment Monitoring Program
- Mortandad/Sandia Chromium Investigation and General Surveillance
- Sandia Wetlands Performance Monitoring Program
- Supplemental Environmental Program

[8] Figure 5-1 presents the sampling distribution similar to Figure 3-2 but across years instead of seasons.

Each of the sampling programs is associated with a sampling and analysis plan, which describes the sampling and analytical QA/QC for that program. Because they rely on similar samples and analytical data, these plans are comparable in scope and content.

3.4.2 Laboratory analysis and data validation

LANL contracted with several laboratories to analyze its surface water data between 2005 and 2019:

- General Engineering Laboratories, Inc., Charleston, South Carolina
- Environmental Sciences Division, Los Alamos, New Mexico
- Desert Research Institute, Reno, Nevada
- Cape Fear Analytical, Wilmington, North Carolina
- Brooks Applied Laboratories, Bothell, Washington

LANL's contract laboratories analyze the samples using standard analytical methods, usually EPA methods. The following methods are used:

- EPA 150.1 (pH)
- EPA 310.1 (alkalinity)
- SM-A2340B (hardness)
- SW-9060 (organic carbon)
- EPA 300.0 (anions – sulfate and chloride)
- EPA 200.7 and 200.8 and SW-846 methods 6010C, 6020, and 6020b (metals by inductively coupled plasma)

Each analytical method is considered appropriate and scientifically defensible for analysis of BLM parameters (EPA 2007b).

LANL's contract laboratories follow standard QA/QC procedures for analysis and data reporting and are accredited under the DOE Consolidated Audit Program for the analytes of interest. Detection and reporting limits are provided with samples, and non-detections are flagged by the laboratory and checked by independent data validators. Appendix A provides the detection status for each sample in the copper SSWQC database. When copper was not detected, reported results in Appendix A are equal to the detection limit.

N3B data validation is performed externally from the analytical laboratory and end-users of the data. This data validation process applies a defined set of performance-based criteria to analytical data that may result in the qualification of that data. Data validation provides a level of assurance, based on this technical evaluation, of the data quality.

Laboratory analytical data are validated by N3B personnel as outlined in N3B-PLN-SDM-1000, Sample and Data Management Plan; N3B-AP-SDM-3000, General Guidelines for Data Validation; N3B-AP-SDM-3014, Examination and Verification of Analytical Data; and additional method-specific analytical data validation guidelines. All procedures have been developed, as applicable, from the EPA QA/G-8 *Guidance on Environmental Data Verification and Data Validation* (EPA 2002), *Department of Defense/Department of Energy Consolidated Quality Systems Manual (QSM) for Environmental Laboratories* (DoD and DOE 2019), and the EPA national functional guidelines for data validation (EPA 2017, 2020).

N3B validation of chemistry data includes a technical review of the analytical data package. This review covers the evaluation of both field and laboratory QC samples, the identification and quantitation of analytes, and the effect of QA/QC deficiencies on analytical data, as well as other factors affecting data quality.

The analytical laboratory uploads the data as an electronic data deliverable to the N3B Environmental Information Management (EIM) database. The data are then validated both manually and using EIM's automated validation process. Validated results are reviewed by an N3B chemist before being fully transferred to the EIM database.

This validation follows processes described in the N3B validation procedures listed above. Validation qualifiers and codes applied during this process are also reviewed and approved by an N3B chemist to assess data usability. The EIM data are then made available to the public in the Intellus New Mexico database (Intellus 2019). Any data rejected during data validation were not used to develop the copper SSWQC. Additionally, any data in Intellus with a BEST_VALUE_FLAG reported as "N" was excluded.[9]

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[9] Some surface water samples were analyzed multiple times for the same analyte, with each analytical result being reported in Intellus; one of those measurements may have been flagged as the "best." Data reported with a BEST_VALUE_FLAG of "Y" in Intellus were used to develop the copper SSWQC, whereas those with a flag of "N" were excluded.

4 Methods for Developing SSWQC

The following sections describe the technical and regulatory basis for the BLM and the resulting MLR-based SSWQC, which were developed using BLM input and output data (Appendix A).

4.1 Background on the BLM

The copper BLM is a software tool that mechanistically describes, and can predict, the bioavailability of copper under a wide range of water chemistry conditions observed in ambient surface waters. The copper BLM is scientifically robust and defensible, EPA recommended, and freely available. BLMs have been developed for metals in both freshwater and saltwater environments; however, to date, EPA has only released nationally recommended BLM-based WQC for copper. A general schematic for the BLM is depicted in Figure 4-1; arrows show the mechanistic relationships among various water quality parameters, the dissolved metal ("Me^{n+}"), and the biotic ligand, represented by the gill surface of an aquatic organism (or a homologous respiratory organ).

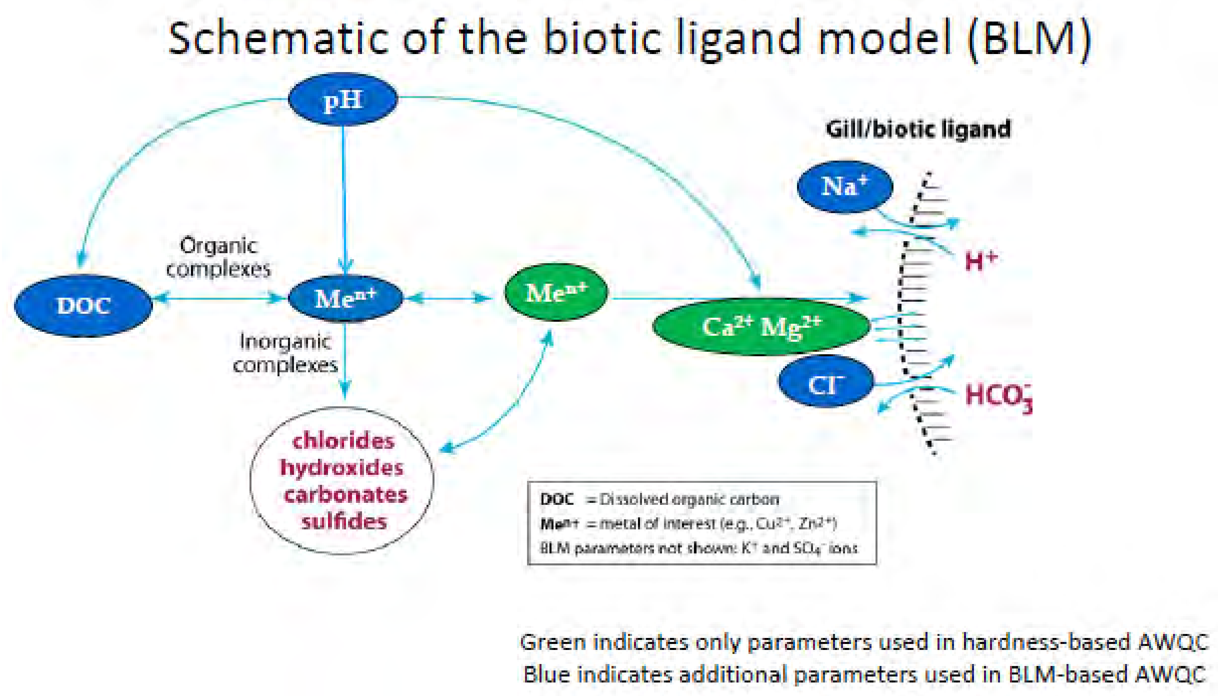


Figure 4-1. Schematic of the BLM

The BLM executable program that drives the Windows Interface version of the BLM software can be used to perform BLM calculations efficiently for large datasets. The Windows Interface version of the software (version 3.41.2.45) was used when developing this report.

The BLM's ability to incorporate metal speciation reactions and organism interactions allows for the prediction of metal effect levels associated with a variety of organisms over a wide range of water quality conditions. Accordingly, the BLM is a defensible and relevant method for deriving WQC across a broad range of water chemistry and physical conditions (EPA 2007a). It generates both acute (i.e., Criterion Maximum Concentration [CMC]) and chronic (i.e., Criterion Continuous Concentration [CCC]) criteria applicable to all aquatic life use categories specified in 20.6.4.10 NMAC.

The copper BLM is also applicable to stormwater flow and NPDES benchmarks. In 2019, EPA sponsored a study conducted by the National Academies of Sciences, Engineering, and Medicine's National Research Council for updating stormwater benchmarks under EPA's MSGP program (NAS 2019). Based on that study, EPA (2021) recommends that the copper BLM be used to derive stormwater benchmarks in accordance with EPA 304(a) guidance. EPA has also included stipulations for the use of the copper BLM at industrial facilities as part of the 2021 MSGP; the BLM may be used to show whether facility-specific discharge concentrations that exceed the generic MSGP copper benchmarks are in compliance.

4.2 Description of BLM Inputs and Functions

The copper BLM (EPA 2007a) utilizes 12 water quality parameters: pH, DOC, calcium, magnesium, sodium, potassium, sulfate, chloride, alkalinity, temperature, percent humic acid (%HA), and sulfide. While %HA is an input parameter, it is rarely measured in ambient surface waters, so the BLM user's guide recommends a default value of 10% (HydroQual 2007; Windward 2017). The selected default value for total sulfide was the recommended value from Windward (2019) of 1×10^{-10} mg/L, which is appropriate when sulfide data are not available. Total sulfide does not influence the copper BLM, however a small non-zero value is required to calculate BLM output. Measured copper concentrations are not needed to generate BLM WQC. All BLM inputs and outputs for Pajarito Plateau samples can be found in Appendix A.

EPA (2007a, 2016b) provides guidance for developing datasets suitable for generating BLM-based copper WQC, including how a given parameter can be estimated from other parameters or regional datasets or set to a default value. A general overview of these approaches is described below. Section 5.1 and Appendix B describe the development of the site-specific BLM dataset for the Pajarito Plateau.

Generally, measured concentrations in water samples that have been filtered through a 0.45-µm filter (i.e., operationally defined as dissolved concentrations) are used as BLM inputs. If it can be demonstrated that dissolved and total (unfiltered) concentrations of BLM inputs are similar, then total concentrations can be substituted for dissolved concentrations if the latter are not available for a given sample.

In addition to substitution approaches, it may be necessary to estimate concentrations for some BLM input parameters based on other measured parameters. For example, calcium and magnesium may be estimated from hardness, DOC may be estimated

from total organic carbon (TOC), and other cations or anions may be estimated from their relationships with conductivity or specific conductance. This estimation approach is contingent upon a demonstration that such estimates are appropriate and defensible.

Another approach to substituting missing BLM inputs makes use of the ecoregion-specific "default" estimates proposed by EPA (2016b). Oregon uses this approach to generate "default" copper WQC for purposes of initial screening assessments (Oregon DEQ 2016a, b; McConaghie and Matzke 2016), although state-specific datasets are used rather than EPA (2016b) values. This approach was not needed when aggregating data for the Pajarito Plateau for the analysis described herein, because sufficient water quality data were available (Section 5.1).

4.3 USE OF MLR IN DEVELOPING WQC

An MLR approach was used to develop a site-specific, three-parameter equation that accurately predicts BLM-based copper WQC for surface waters of the Pajarito Plateau using pH, DOC, and hardness values (Sections 5.3, 5.4, and 6). This approach parallels the one adopted in Georgia in 2016, whereby a two-parameter, BLM-based MLR equation was approved by EPA as the copper SSWQC for Buffalo Creek (Resolve 2015; EPA 2016a).[10] The MLR approach, where shown to be robust and accurate, significantly reduces sampling and analytical costs compared to using the full BLM, while still incorporating the BLM's scientific rigor.

EPA has commonly used linear regression to derive its nationally recommended WQC, most of which have been adopted in New Mexico WQS for metals and ammonia. EPA currently uses a simple linear regression with hardness as the independent variable to derive aquatic life criteria for cadmium, chromium, lead, nickel, silver, and zinc. EPA uses a two-parameter linear regression to derive aquatic life criteria for ammonia, using temperature and pH as independent variables. In 2018, EPA used a three-parameter MLR equation (using pH, DOC, and hardness) as the basis for its nationally recommended aquatic life criteria for aluminum (EPA 2018b). EPA is also currently evaluating MLRs as the potential bases of WQC for other metals (EPA 2018a). MLRs have been used by others to describe the effects of water chemistry on the bioavailability and toxicity of metals (EPA 1987; Esbaugh et al. 2012; Fulton and Meyer 2014; Rogevich et al. 2008), including in the development of copper WQC (Brix et al. 2017).

Thus, strong scientific and regulatory rationale exists for using the MLR approach to develop relatively simple equations that account for the effects of water chemistry on metal bioavailability.

[10] The two parameters used for Buffalo Creek were pH and DOC (Resolve 2015).

MLRs can be evaluated by how well they match BLM predictions, a process described in Section 5. An MLR equation that matches copper BLM WQC well yields criteria that are consistent with best available science and with EPA's nationally recommended WQC (EPA 2007a). Using an MLR equation has the benefit of being a transparent and readily available regulatory option that can incorporate EPA (2007a) BLM-based copper WQC into New Mexico WQS as SSWQC for surface waters of the Pajarito Plateau, without the need for BLM software and training.

5 Data Evaluation

This section describes the development of the Pajarito Plateau BLM dataset for the purpose of generating BLM-based copper WQC output. It also describes how those outputs were used to generate MLR equations for the Pajarito Plateau (i.e., the copper SSWQC).

5.1 DQO/DQA Process and BLM Dataset

In 2018, EPA's data quality objective/data quality assessment (DQO/DQA) process was used to select appropriate BLM datasets for several metals (including copper) and determine their usability for performing BLM-based WQC calculations consistent with EPA guidance (Windward 2018b; EPA 2007a).

Both Appendix B to this report and Windward's DQO/DQA report (2018b) provide additional information on the DQO/DQA process used to develop a scientifically defensible set of BLM input data. Each step of the 2018 DQO/DQA process pertaining to developing copper BLM inputs is summarized below:

1) **State the problem.** New Mexico's hardness-based copper criteria do not reflect the best available science regarding copper bioavailability and toxicity. Therefore, using the existing copper WQC may lead to erroneous conclusions about whether copper concentrations are protective of aquatic life, as well as erroneous decisions about management actions needed to protect aquatic life.

2) **Define study objectives.** The objectives were to identify and use appropriate data to generate BLM-based criteria for locations on or around the Pajarito Plateau near the Laboratory.

3) **Identify information inputs.** Inputs were sufficiently complete sets of BLM input parameters from discrete water sampling events in surface waters of the Pajarito Plateau. Water chemistry data used for BLM calculations were collected under a defined sampling plan using defensible sampling and analytical methods, QC review, and data validation procedures. The primary source of information for this evaluation was surface water monitoring data collected by LANL (Section 3.4; Appendix A; Appendix B, Section B2).

4) **Define study boundaries**. Temporal boundaries included the time periods over which sufficiently complete BLM input data exist for surface waters of the Pajarito Plateau. Surface water sampling events included either some form of dry weather baseflow (e.g., effluent, springs, and/or snowmelt) or stormflow generated by rainfall. Spatial boundaries included all surface water locations on the Pajarito Plateau in the vicinity of the Laboratory that have sufficient BLM datasets.

5) **Develop an analytical approach.** The overall analytical approach entailed 1) compiling a source dataset from LANL's EIM database, 2) aggregating and evaluating data to determine the extent to which BLM-based criteria can be generated for each discrete event in accordance with available EPA (2007b) guidance (Appendix B, Section B2), and 3) calculating BLM-based "instantaneous criteria" using the EPA (2007a) copper BLM (Section 5.2) for each discrete event with sufficient BLM inputs.

6) **Specify performance and acceptance criteria.** The performance and acceptance criteria for developing an appropriate dataset were primarily based on whether sufficient water chemistry data were available to generate BLM-based WQC for the locations of interest. Specifically, BLM-based calculations were performed only when, at a minimum, pH and organic carbon were measured for the same water sampling event. As appropriate, substitutions or estimations of missing BLM input parameters were conducted as possible from available data, for example using a mathematical relationship between dissolved and total concentrations, substituting the average concentration for a given location, and/or using EPA guidance for such estimations. Acceptance criteria included that 1) samples were collected in ambient surface waters (i.e., within AUs) rather than from storm water runoff locations in developed areas; 2) data used for BLM calculations were validated; and 3) models used for calculations were applicable and defensible for calculating WQC.

7) **Develop a plan for obtaining data**. As discussed in Section 3.4, surface water data, including BLM inputs, have been collected by LANL at many locations since 2005. To perform the analyses described above, water quality data from the EIM database associated with receiving water samples were queried by LANL contractors, and the results were provided to Windward as a spreadsheet. Supplemental water quality data for the Rio Grande were obtained from National Water Quality Monitoring Council's online Water Quality Portal database (National Water Quality Monitoring Council 2019).

The outcome of this process, when applied to LANL's surface water data, was the establishment of a BLM database with sufficient quality and quantity to develop SSWQC for Pajarito Plateau waters and to compare those criteria to existing criteria for copper and other metals. Staff from NMED[11] participated in the review of the DQOs and the 2018 DQO/DQA report.

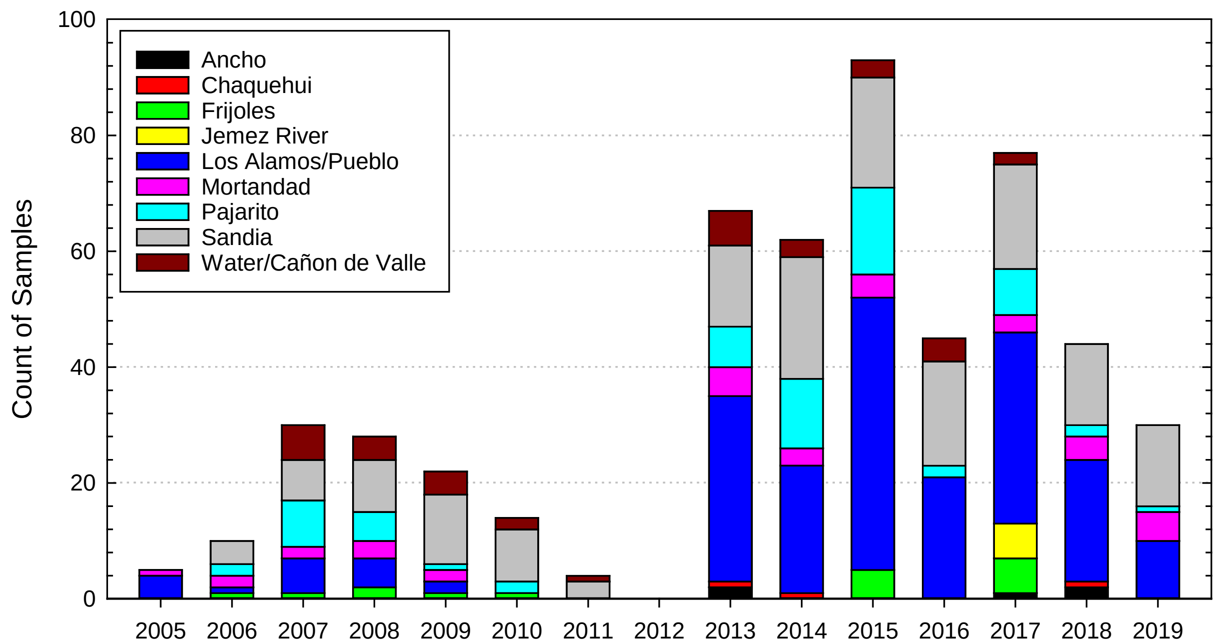
[11] NMED staff from the SWQB and DOE Oversight Bureau participated in kickoff meetings in March 2018, and they submitted comments on the draft DQO/DQA report that were addressed in the April 2018 BLM DQO/DQA report. NMED staff also participated in an October 2018 webinar with EPA Region 6 staff to review and discuss the BLM findings and their potential use as stormwater monitoring TALs for copper, lead, and zinc in the context of the IP.

For this demonstration, the 2018 DQO/DQA process was applied to a water quality dataset that included BLM data collected through 2019 (i.e., two additional years of monitoring data not assessed in the 2018 DQO/DQA report). The complete BLM dataset for the Pajarito Plateau is provided in Appendix A. The source dataset was generated by LANL/N3B (Section 3.4), uploaded to the EIM database, and then exported and provided to Windward by N3B. In addition to analytical data, N3B provided information about sampling locations to support interpretation of the BLM dataset. This information included major and minor watershed names, location classifications related to land use (i.e., undeveloped or downstream of a LANL site), and information on the type of water sample (e.g., surface water, snowmelt, persistent flow, or storm water runoff).

After receiving the source dataset from N3B, Windward aggregated water quality data to establish sufficient input parameters to generate BLM-based copper WQC for each discrete sampling event. Further information on the DQO/DQA process and data aggregation steps used to construct the complete BLM dataset for the Pajarito Plateau is provided in Appendix B (Section B2).

The complete BLM dataset for the Pajarito Plateau spans the period from 2005 to 2019 and includes a total of 531 discrete samples collected from 50 locations across 9 large watersheds.[12] Figure 5-1 shows a breakdown of when and where the 531 BLM samples in the final dataset were collected. Map 3-1 shows each surface water monitoring location. Figures 5-2 and 5-3 show the distributions of water quality parameters in the full dataset (Appendix A).

[12] Ultimately, 517 samples were used for MLR development; 14 samples with pH, DOC, and/or hardness values outside the prescribed ranges for the BLM were removed.



Note: No samples in the final BLM dataset were collected in 2012 due to drought conditions.

Figure 5-1. Distribution of BLM samples by watershed and over time, 2005 to 2019

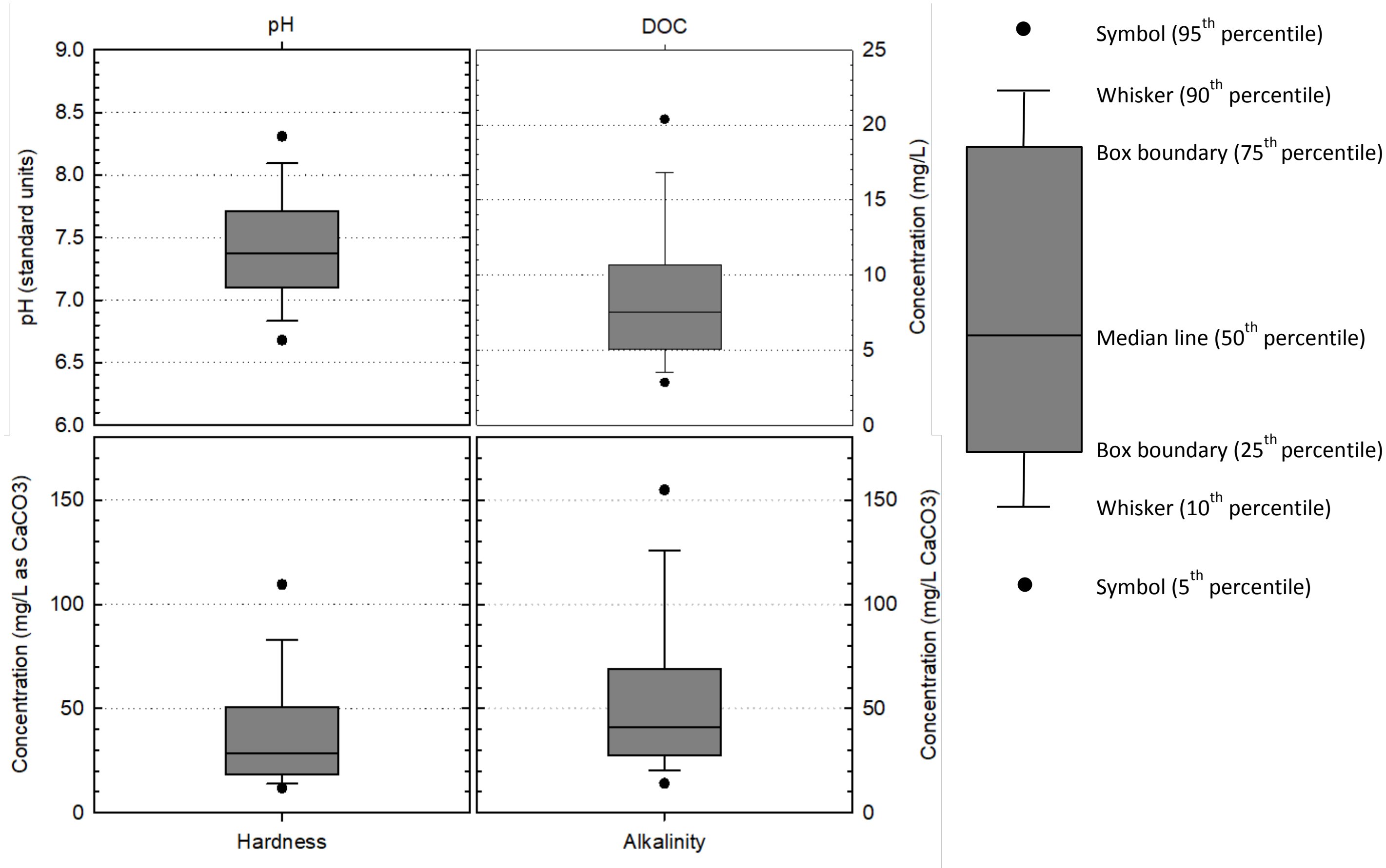
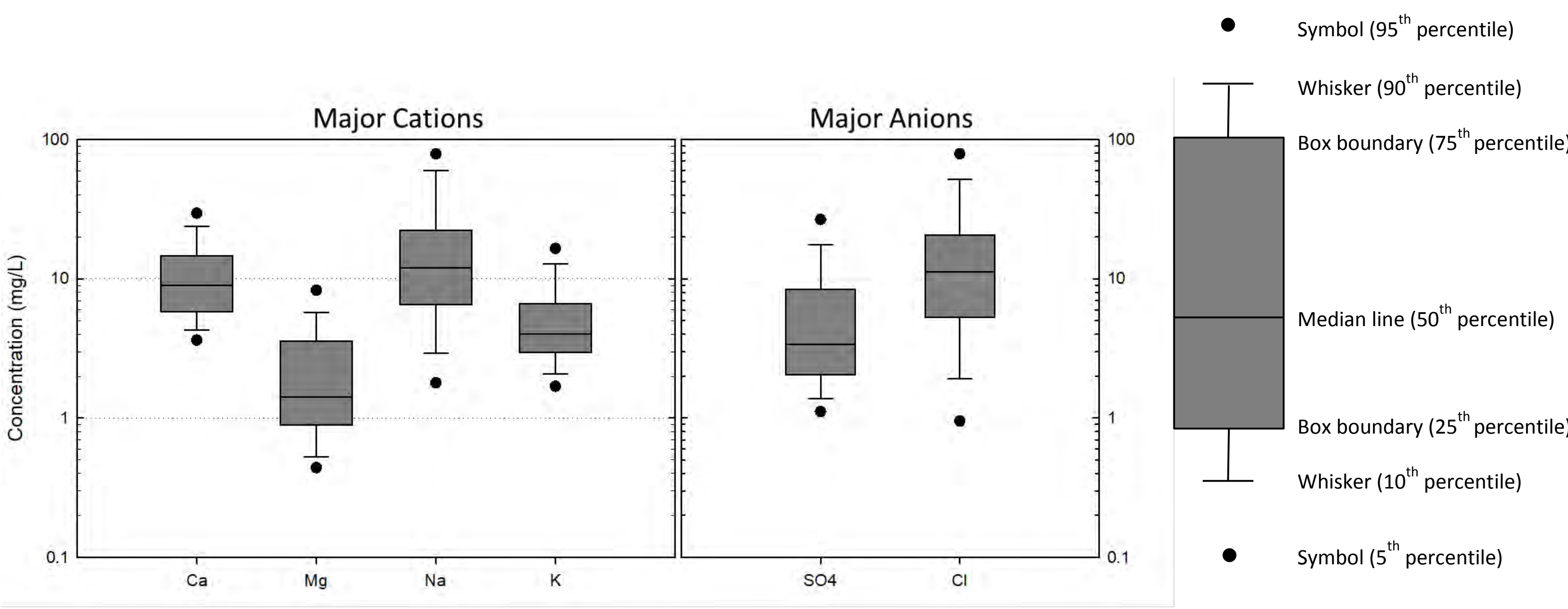


Figure 5-2. Distributions of water quality inputs to the MLR and/or BLM



Note: The following water chemistry parameters are shown: calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), sulfate (SO4), and chloride (Cl).

Figure 5-3. Distributions of major cation and anion inputs to the BLM

As discussed in this report and in Appendix B, hydrology was investigated in detail when developing copper SSWQC, because of the various hydrological classifications of surface waters on the Pajarito Plateau (i.e., ephemeral, intermittent, and perennial). According to New Mexico WQS, chronic and acute WQC apply in specific watersheds based on their respective hydrologic classifications, so the proposed acute and chronic SSWQC, if adopted, would apply similarly. For the purposes of developing and testing MLR equations to accurately estimate BLM WQC, hydrology data were characterized using existing NMAC hydrologic classifications for surface waters of the Pajarito Plateau. Table 5-1 shows a tabular breakdown of samples by major watershed and current NMAC hydrologic classification. Additionally, Appendix B (Section B5.2.3) provides an investigation of potential updated classifications based on the most recent hydrology protocol efforts by NMED and LANL.

Table 5-1. New Mexico WQS hydrologic classification assignments for the BLM dataset by major watershed

Major Watershed	NMAC Hydrological Classification			N by Watershed
	Ephemeral/ Intermittent (20.6.4.128)	Default Intermittent (20.6.4.98)	Perennial (20.6.4.121/ 20.6.4.126)	
Ancho	5	0	0	**5**
Chaquehui	3	0	0	**3**
Frijoles	0	9	8	**17**
Jemez River	0	6	0	**6**
Los Alamos/Pueblo	142	62	0	**204**
Mortandad	28	6	0	**34**
Pajarito	62	0	3	**65**
Sandia	8	0	154	**162**
Water/Cañon de Valle	4	12	19	**35**
N by Hydrology Class	**252**	**95**	**176**	**531**

N – sample size
BLM – biotic ligand model
NMAC – New Mexico Administrative Code
WQS – water quality standard

5.2 BLM Execution

The final BLM dataset (Section 5.1; Appendix A) was input into the copper BLM software (version 3.41.2.45) (Windward 2018a) to generate acute and chronic BLM-based WQC for all samples.[13] These WQC were equivalent to EPA's 2007 copper WQC for freshwater (EPA 2007a) and were used in conjunction with water quality parameters to develop the copper MLR equations. The reduction of the full suite of

[13] The most recent BLM software is accessible through the Windward website: https://www.windwardenv.com/biotic-ligand-model.

BLM parameters to pH, DOC, and hardness for use in the MLR approach is summarized in Sections 5.3 and 5.4.

5.3 BLM Simplification

LANL is proposing MLR equations that will predict BLM-based copper WQC for surface waters of the Pajarito Plateau in the vicinity of the Laboratory. This approach acknowledges both the advantages of the BLM—incorporating the effects of multiple water-quality parameters on copper bioavailability and toxicity—and the challenges—measuring BLM parameters across a large area with a range of water quality and flow conditions. Estimating BLM copper WQC accurately using fewer parameters than the full list of 12 inputs will facilitate copper evaluations.

As described in Section 5.1, site-specific water quality data were collated from 531 samples from 50 locations from 2005 to 2019 (Appendix A). A set of 517 samples spanning 8 watersheds[14] was carried forward to the first round of MLR modeling; 14 samples were removed due to DOC, hardness, or pH concentrations being outside of the prescribed ranges (Table 5-2) for the BLM. Thus, the water quality conditions in Pajarito Plateau surface water samples spanned the entire range of conditions considered reasonable for use in the copper BLM. Modeling methods are summarized in Section 5.4.1 and detailed in Appendix B.

Table 5-2. Prescribed ranges for BLM input parameters

BLM Parameter	BLM Prescribed Range	
	Minimum	Maximum
DOC	0.05	29.65
Hardness	7.9	525
pH	4.9	9.2

Source: Windward (2019)

BLM – biotic ligand model

DOC – dissolved organic carbon

Table 5-3 presents the results of a Spearman correlation analysis (i.e., Spearman rho values) that further substantiate the importance of pH, DOC, and hardness in calculating SSWQC for the Pajarito Plateau. This table illustrates correlations among the three parameters and other BLM input parameters.

[14] The six samples from the Jemez River watershed (Table 5-1) were not carried forward to the MLR analysis because hardness concentrations were < 7.9 mg/L as calcium carbonate (the minimum prescribed concentration for the BLM). Thus, the number of watersheds in the MLR dataset was eight, not nine.

Table 5-3. Spearman correlation analysis results (rho)

Parameter	BLM CMC	BLM CCC	pH	DOC	Hardness	Calcium	Magnesium	Sodium	Potassium	Sulfate	Chloride	Alkalinity
BLM CMC	–	–	0.57	0.54	0.42	0.41	0.43	0.38	0.57	0.45	0.36	0.55
BLM CCC	–	–	0.57	0.54	0.42	0.41	0.43	0.38	0.57	0.45	0.36	0.55
pH	0.57	0.57	–	-0.29	0.57	0.57	0.53	0.5	0.36	0.5	0.44	0.66
DOC	0.54	0.54	-0.29	–	-0.09	-0.09	ns	-0.17	0.23	ns	-0.14	ns
Hardness	0.42	0.42	0.57	-0.09	--	0.99	0.92	0.63	0.63	0.73	0.54	0.83
Calcium	0.41	0.41	0.57	-0.09	0.99	–	0.86	0.6	0.6	0.69	0.52	0.82
Magnesium	0.43	0.43	0.53	ns	0.92	0.86	–	0.64	0.71	0.78	0.55	0.8
Sodium	0.38	0.38	0.5	-0.17	0.63	0.6	0.64	–	0.7	0.8	0.91	0.62
Potassium	0.57	0.57	0.36	0.23	0.63	0.6	0.71	0.7	–	0.72	0.61	0.66
Sulfate	0.45	0.45	0.5	ns	0.73	0.69	0.78	0.8	0.72	–	0.76	0.68
Chloride	0.36	0.36	0.44	-0.14	0.54	0.52	0.55	0.91	0.61	0.76	–	0.54
Alkalinity	0.55	0.55	0.66	ns	0.83	0.82	0.8	0.62	0.66	0.68	0.54	–

Note: All values are Spearman correlation coefficients, which can range from -1 to 1. Only significant correlations are reported (alpha = 0.05); color shading indicates relative strength of correlation (with blue being positive values and red being negative). BLM CMC and CCC correlations are identical because the acute and chronic BLM values differ only by an acute-to-chronic ratio.

– Not Applicable

BLM – biotic ligand model

CMC – criterion maximum concentration

CCC – criterion continuous concentration

DOC – dissolved organic carbon

ns – not significant

Table 5-3 shows that the strongest correlations with BLM output (i.e., CMC and CCC) are for pH (rho = 0.57), potassium (rho = 0.57), alkalinity (rho = 0.55), and DOC (rho = 0.54). Thus, pH and DOC are reasonable to retain for a simplified model, because they have relatively strong correlations and are well supported by the literature regarding mechanisms affecting copper bioavailability (i.e., copper speciation and complexation). While hardness is marginally less correlated with BLM output (rho = 0.44) than are other parameters, hardness is significantly correlated ($p < 0.05$) with pH, calcium, magnesium, sodium, potassium, sulfate, chloride, and alkalinity. Consequently, including hardness in the simplified version incorporates the influence of these parameters on BLM output and builds upon New Mexico's current hardness-based copper criteria in response to which LANL has already collected a substantial amount of hardness data.

While potassium is relatively correlated with the BLM output, sensitivity analyses of the copper BLM established that it is not as mechanistically significant as pH, DOC, or hardness.[15] In their development of a copper BLM specific to the cladoceran *Daphnia magna*, De Schamphelaere and Janssen (2002) evaluated the influence of calcium, magnesium, sodium, potassium, and pH and found that potassium was the only parameter considered that did not affect toxicity. Brix et al. (2017) found that MLR models using only pH, DOC, and hardness (without other parameters) predicted copper toxicity values with a level of accuracy comparable to that of the copper BLM. From a statistical standpoint, parsimonious models are preferable to those including many intercorrelated variables, which can result in "overfitting."[16] Therefore, the importance of potassium for modeling BLM output was viewed skeptically when developing MLRs.

5.4 MLR Equation Development

This section describes the development of acute and chronic MLR equations using BLM input parameter data and corresponding BLM outputs (i.e., BLM-based WQC). For the MLR evaluations, DOC and hardness were transformed using the natural logarithm. This transformation was not required for pH, since it is already on a logarithmic scale. The evaluations were conducted primarily for the acute BLM WQC, because EPA (2007a) applies an acute-to-chronic ratio to generate chronic BLM WQC. As a result, the acute and chronic BLM WQC for copper vary by a constant factor (i.e., 1.61), regardless of water chemistry. Therefore, the following evaluations regarding the development of a best-fit MLR equation are applicable to both acute and chronic copper WQC.

[15] Personal communication, Robert Santore (developer of the copper BLM).

[16] An overfitted MLR will generally predict the underlying dataset better than a simpler model, but it is less likely to predict future data with similar accuracy. Overfit models are overly specific.

5.4.1 Methods

Many candidate MLRs were developed, evaluated, and compared using standard statistical and visual methods, which included statistics related to each model's goodness-of-fit (e.g., adjusted R^2) and model assumptions (e.g., tests of the normality and homoscedasticity of residuals). Visual tools were used to evaluate model fit and to facilitate model refinements (Appendix B, Section B4).

The development of models followed several general steps iterated over several rounds of modeling. First, a basic model was tested that contained only pH, DOC, and hardness, consistent with previously developed MLR models (Brix et al. 2017) and the simplified BLM (Windward 2019). These three water quality parameters affect copper speciation (e.g., pH), complexation with the free cupric ion ($copper^{2+}$) (e.g., DOC), and competition with copper at a site of uptake by the organism (e.g., $calcium^{2+}$ represented by hardness and $hydrogen^{+}$ represented by pH). As such, they capture the primary mechanisms affecting copper bioavailability that underpin the copper BLM.

Once this baseline model was established, various other, more complex models that included additional parameters were developed. For example, models included different slopes and/or intercepts for ephemeral/intermittent, intermittent, and perennial NMAC classifications. The development of these models was followed by a stepwise regression step, wherein the statistical software was allowed to test many permutations of the larger model by adding or removing the hydrologic slopes and intercepts and checking the goodness-of-fit of each permutation.[17] This step provided information about which of the variables in the most complex model might be important and which could be excluded during the model refinement step. The final step, model refinement, involved both the removal of unimportant variables and the addition of a new variable, squared pH (pH^2), to eliminate patterns observed in the model residuals (Figure 5-4).

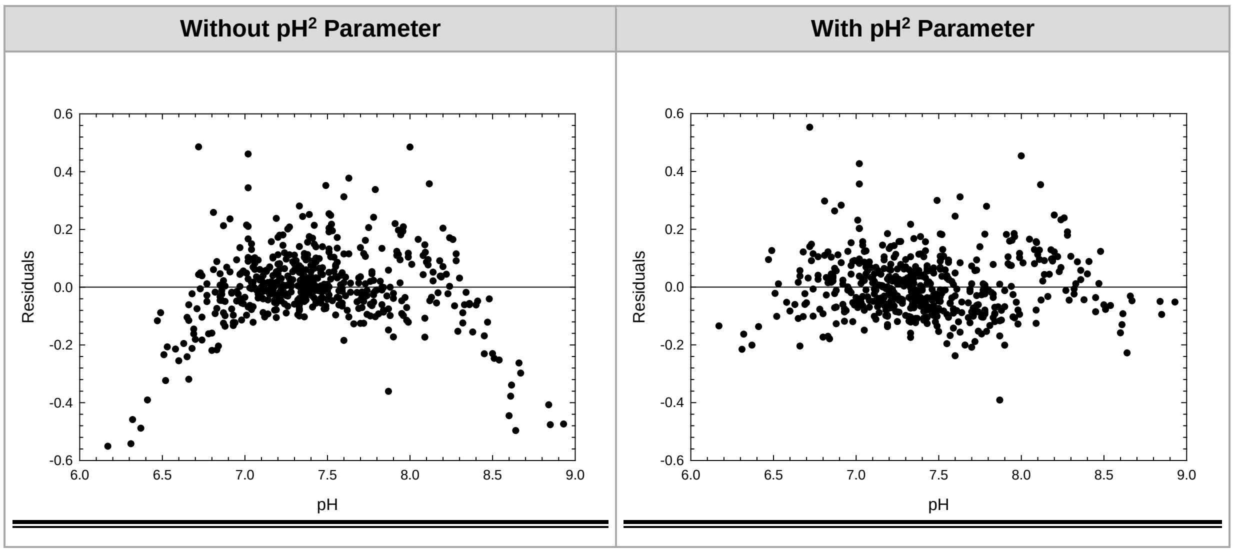
5.4.2 Results

A detailed discussion of the development of MLR equations is provided in Appendix B, Section B4. This section provides a summary of those findings and the stepwise MLR analyses that led to the proposed MLR equations for copper SSWQC.

As noted in Section 5.4.1, MLRs were developed over several rounds. The first round started with a simple model using pH, DOC, and hardness as the independent variables to predict BLM-based WQC. This model resulted in a very high adjusted R^2 of 0.969, indicating that 96.9% of the variation in BLM-based WQC can be accounted for by these three parameters.

[17] This step was limited to hydrological classification parameters, slopes, and intercepts. DOC, pH, and hardness were retained throughout the stepwise analysis.

More complex models including pH, DOC, and hardness, as well as hydrology-specific slopes and intercepts for the ephemeral/intermittent, intermittent, and perennial classifications, were considered in the second round. While evaluating this model structure, it was observed that MLR model residuals (i.e., difference between BLM WQC and MLR-predicted WQC) and pH had a curvilinear relationship (Figure 5-4, left panel). To address this, a pH^2 term was added to the model in the third round; this eliminated the curvilinear pattern in residuals (Figure 5-4, right panel).



Note: Horizontal line at a residual of zero indicates perfect prediction.

Figure 5-4. Comparison of MLR model residuals with and without a pH^2 parameter

After including the pH^2 term, models without hydrology factors were also developed as part of the third round of modeling. Comparisons of summary statistics among these various models (Table 5-4), analysis of residuals (Appendix B, Section B4), and consideration of the magnitudes of differences among models led to the conclusion that the use of hydrology-specific slopes and intercepts did not result in better MLR equations compared to the use of less complex (i.e., more parsimonious) models. For example, after removing all hydrological classification parameters from the MLR in the third round of modeling, the adjusted R^2 changed from 0.983 to 0.980, meaning that hydrology classification explained only 0.3% of the variation not already explained by pH, DOC, and hardness. From a practical standpoint, the added complexity of hydrological classification was not needed to accurately predict BLM output. Moreover, because the NMAC classes are subject to change over time (e.g., default intermittent waters are potentially reclassified through the hydrology protocol process), to include hydrologic classification could lead to unnecessary ambiguity in future applications of the MLR.

Table 5-4. Summary statistics of MLR models fit to BLM WQC

Model Description	Development Method[a]	Adjusted R^2	Predicted R^2	AIC	BIC	Shapiro-Wilk Test p-value[b]	Scores Test p-value[c]
Simplest model; includes pH, DOC, and hardness only (no distinction in hydrology)	full	0.969	0.968	-614	-593	<0.001	0.249
Hydrology slopes and intercepts	full	0.973	0.971	-677	-621	<0.001	0.751
	AIC	0.973	0.971	-681	-643	<0.001	0.704
	BIC	0.973	0.971	-681	-643	<0.001	0.704
Hydrology slopes and intercepts; pH^2 added	full	0.984	0.981	-928	-860	<0.001	0.0476
	AIC	0.984	0.981	-928	-860	<0.001	0.0476
	BIC	0.983	0.981	-918	-876	<0.001	0.00332
Hydrology intercepts only (slopes excluded); pH^2 term always included	full	0.982	0.982	-899	-865	<0.001	0.0204
	AIC	0.982	0.982	-899	-865	<0.001	0.0204
	BIC	0.982	0.982	-899	-865	<0.001	0.0204
No distinction in hydrology; pH^2 term always included; final models (proposed MLRs for copper SSWQC)	full (acute)	0.980	0.979	-833	-808	<0.001	0.083
	full (chronic)	0.980	0.979	-833	-808	<0.001	0.083

[a] Development methods are divided into "full" models (includes all variables indicated in model description) or AIC/BIC stepwise regression models.

[b] Shapiro-Wilk test for normality of residuals; $p < 0.05$ indicates non-normality.

[c] Scores test for homogeneity of residuals; $p < 0.05$ indicates non-constant variance (i.e., heteroscedasticity).

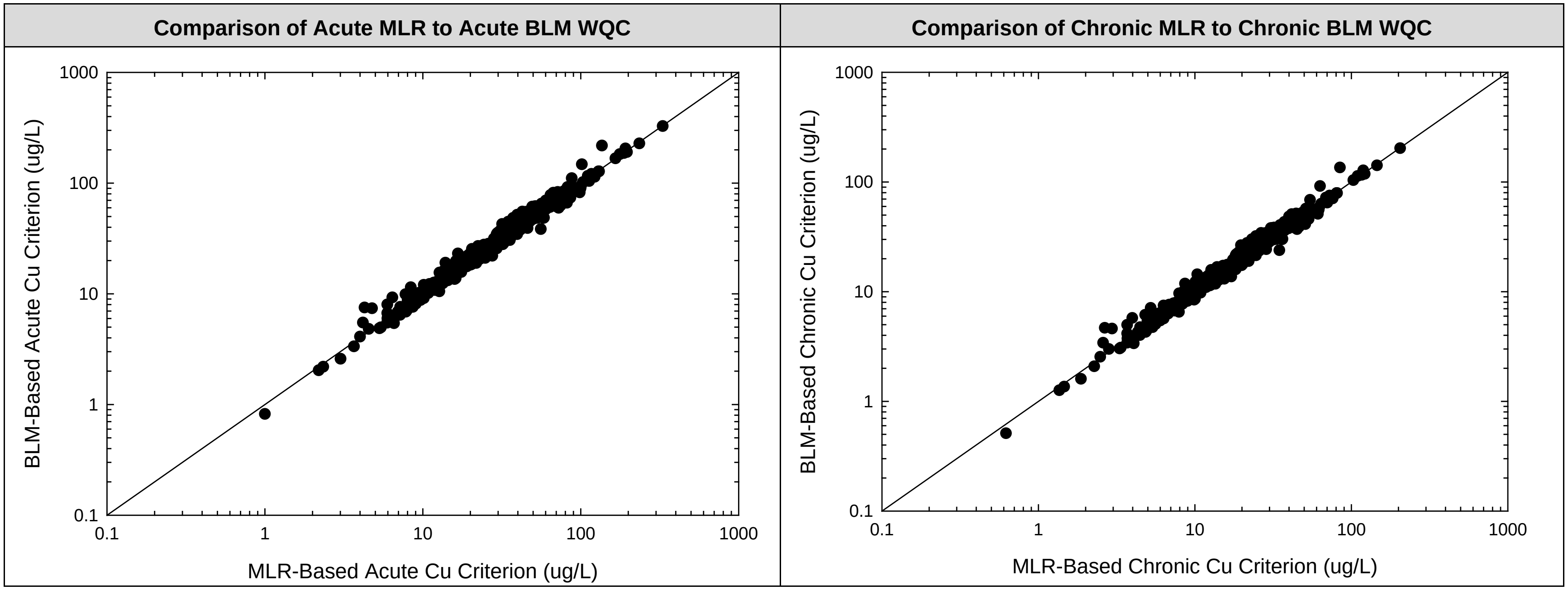
AIC – Akaike's Information Criterion
BIC – Bayesian Information Criterion
BLM – biotic ligand model
DOC – dissolved organic carbon
MLR – multiple linear regression
SSWQC – site-specific water quality criterion
WQC – water quality criterion

After demonstrating that an MLR model including hydrological class is not a substantial improvement over a more parsimonious model, and after including a pH^2 parameter to address residual patterns, Equations 1 and 2 were selected as SSWQC.

$$\boldsymbol{CMC = exp(-22.914 + 1.017 \times ln(DOC) + 0.045 \times ln(hardness) + 5.176 \times pH - 0.261 \times pH^2)} \quad \textbf{Equation 1}$$

$$\boldsymbol{CCC = \mathbf{exp}\ (-23.391 + 1.017 \times ln(DOC) + 0.045 \times ln(hardness) + 5.176 \times pH - 0.261 \times pH^2)} \quad \textbf{Equation 2}$$

Figure 5-5 shows comparisons of MLR-based SSWQC calculations to the equivalent BLM calculations for the Pajarito Plateau dataset. The figure shows that the SSWQC and BLM calculations are very similar between the two approaches (adjusted $R^2 = 0.980$ for the acute and chronic MLRs) and values are distributed evenly across the solid diagonal 1:1 line representing perfect agreement. Therefore, the three-parameter MLR equations provide highly accurate results. In addition, more points fall above the 1:1 line (n = 261) than below (n = 256) in Figure 5-5, indicating that overall, the proposed copper SSWQC equations provide more conservative copper WQC for the Pajarito Plateau than the BLM software.

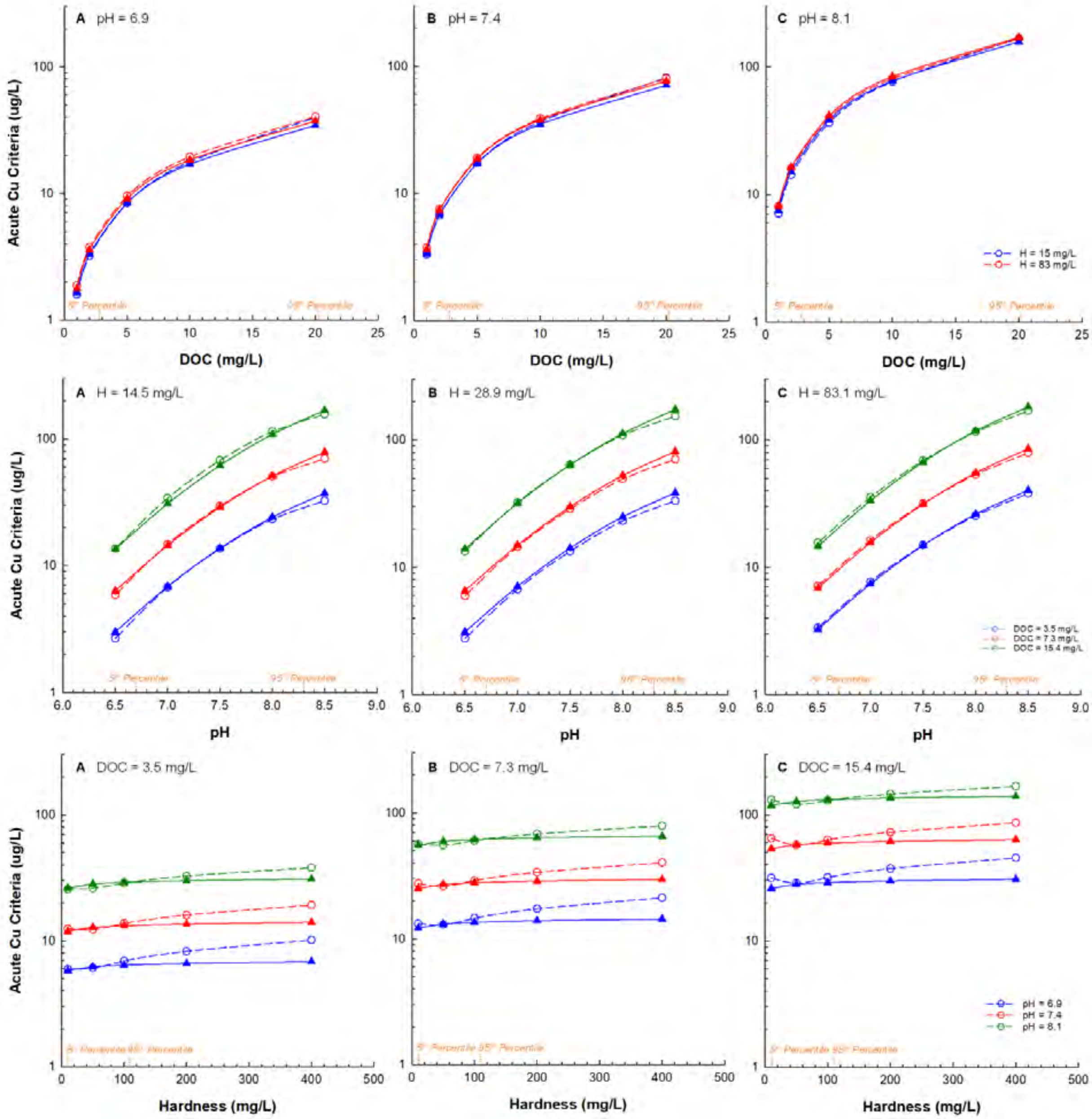


Note: Solid line represents a 1:1 relationship (perfect agreement).

N = 517 samples (BLM dataset for the Pajarito Plateau excluding samples outside the BLM prescribed ranges for pH, DOC, and hardness)

Figure 5-5. Comparison of proposed acute and chronic copper SSWQC predictions to acute and chronic BLM WQC

Figure 5-6 presents an additional comparison of MLR- and BLM-based copper WQC across varying concentrations and combinations of DOC, pH, and hardness.



Note: BLM-based criteria are shown as dashed lines and open circles. MLR-based acute criteria are shown as solid lines and triangles. Blue, red, and green plots represent the 10th, 50th, and 90th percentiles, respectively, in the BLM dataset for the Pajarito Plateau. The 5th and 95th percentiles for each parameter are shown in orange on each x-axis. For comparative purposes, BLM criteria were generated with the "simplified site chemistry" input option using median ion ratios in the site-specific dataset.

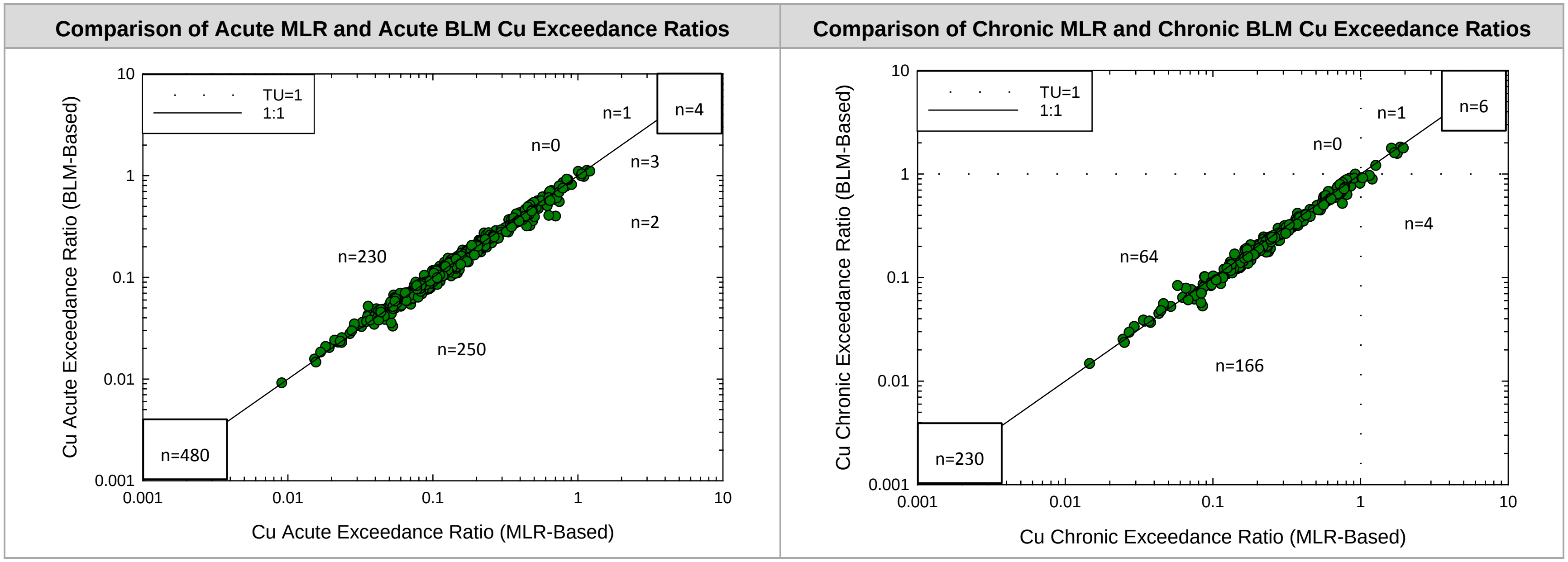
Figure 5-6. Comparison of BLM- and MLR-based acute criteria

Figure 5-6 shows how the MLR- and BLM-based copper WQC vary as a function of DOC (top row), pH (middle row), and hardness (bottom row). For comparative purposes, MLR- and BLM-based copper WQC were generated using various combinations of DOC, pH, and hardness concentrations corresponding to the 10th, 50th, and 90th percentiles in the BLM dataset for the Pajarito Plateau (shown as the colored lines and panels A, B, and C in Figure 5-6). This comparison further demonstrates the consistency between MLR-based copper WQC (solid lines, triangles) and BLM-based copper WQC (dashed lines, open circles) across a wide range of water chemistries. The greatest deviation between the two approaches occurs at high-hardness concentrations (≥ 200 mg/L); however, BLM-based copper WQC are greater than MLR-based copper WQC, indicating that the proposed MLR-based copper WQC are conservative under high-hardness conditions. Furthermore, such conditions are uncommon in surface waters on the Pajarito Plateau, as indicated by the 5th and 95th percentiles shown on the x-axes in Figure 5-6. Overall, the high degree of consistency between BLM- and MLR-based WQC over the range of water chemistries observed throughout the Pajarito Plateau indicates that the proposed MLR equations provide a reliable and scientifically defensible method to accurately estimate EPA's (2007a) nationally recommended copper WQC on a site-specific basis. Appendix B provides additional evaluations of the proposed MLR equations that further substantiate their selection as proposed copper SSWQC.

5.5 Comparison to Current Copper WQC

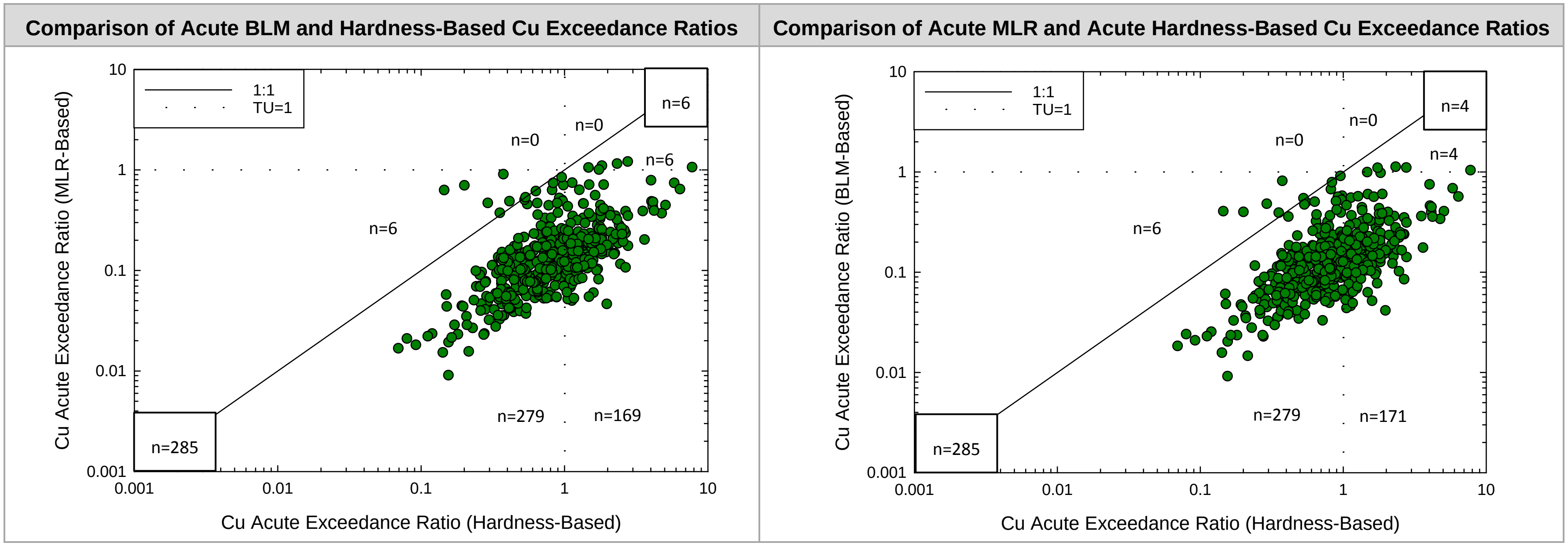
Comparisons of copper exceedance ratios[18] calculated using EPA's (2007a) BLM, the site-specific MLR (Equation 1), and New Mexico's current hardness-based WQC are shown in Figures 5-7 through 5-10. Figure 5-7 compares exceedance ratios for the acute and chronic BLM- and MLR-based criteria. Figure 5-8a compares acute exceedance ratios for the BLM- and MLR-based criteria to acute hardness-based criteria, and Figure 5-8b presents the same comparison for exceedance ratios of the analogous chronic criteria. Figures 5-9 and 5-10 present similar results as boxplots (showing results by watershed) for the acute and chronic criteria, respectively.

[18] Exceedance ratio = measured copper concentration divided by copper WQC.



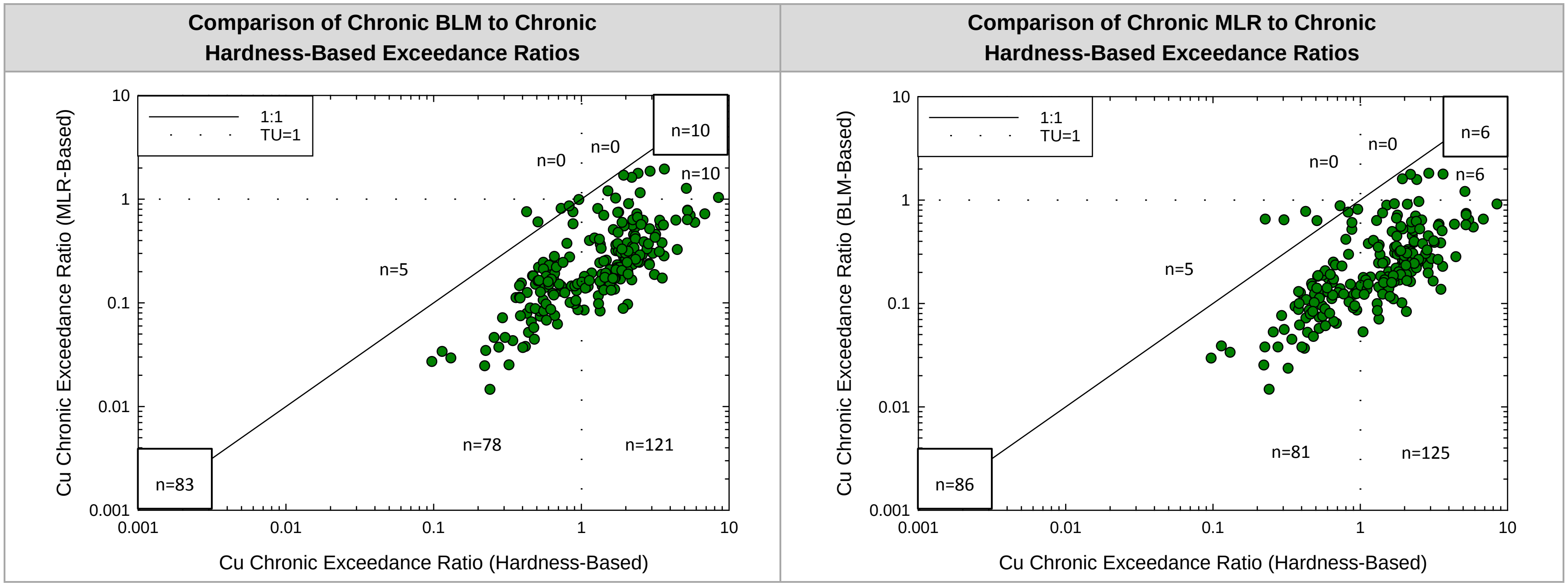
Note: Copper exceedance ratios are measured dissolved copper concentrations divided by a copper criterion. The solid 1:1 line represents perfect agreement between two criteria, and the dashed lines indicate the points at which copper concentrations exceed each criterion. "N" sample sizes represent the counts of samples in subareas of the plot defined by the solid and dashed lines. The "N" values in boxes represent the sums of samples in either the upper right or lower left quadrant, where there is general agreement between the two criteria (i.e., both predict an exceedance or non-exceedance of a copper criterion). The chronic exceedance ratio plot on the right excludes samples collected from locations classified under 20.6.4.128 NMAC in which only the acute criteria apply. Plots exclude samples in the Pajarito Plateau BLM dataset where copper detection limits were greater than BLM calculations.

Figure 5-7. Comparison of copper exceedance ratios between EPA (2007) BLM WQC and site-specific MLR WQC



Note: Copper exceedance ratios are measured dissolved copper concentrations divided by a copper criterion. The solid 1:1 line represents perfect agreement between two criteria, and the dashed lines indicate the points at which copper concentrations exceed each criterion. "N" sample sizes represent the count of samples in subareas of the plot defined by the solid and dashed lines. The "N" values in boxes represent the sums of samples in either the upper right or lower left quadrant, where there is general agreement between the two criteria (i.e., both predict an exceedance or non-exceedance of a copper criterion). Plots exclude samples in the Pajarito Plateau BLM dataset, where copper detection limits were greater than BLM-based or hardness-based WQC.

Figure 5-8a. Comparison of acute copper exceedance ratios between site-specific copper MLR WQC and New Mexico hardness-based WQC, and between EPA (2007) BLM calculations and New Mexico hardness-based WQC



Note: Copper exceedance ratios are measured dissolved copper concentrations divided by a copper criterion. The solid 1:1 line represents perfect agreement between two criteria, and the dashed lines indicate the points at which copper concentrations exceed each criterion. “N” sample sizes represent the count of samples in subareas of the plot defined by the solid and dashed lines. The “N” values in boxes represent the sums of samples in either the upper right or lower left quadrant, where there is general agreement between the two criteria (i.e., both predict an exceedance or non-exceedance of a copper criterion). Plots exclude samples in the Pajarito Plateau BLM dataset, where copper detection limits were greater than BLM-based or hardness-based WQC and samples collected from locations classified under 20.6.4.128 NMAC in which acute only criteria applies.

Figure 5-8b. Comparison of chronic copper exceedance ratios between site-specific copper MLR WQC and New Mexico hardness-based WQC, and between EPA (2007) BLM calculations and New Mexico hardness-based WQC

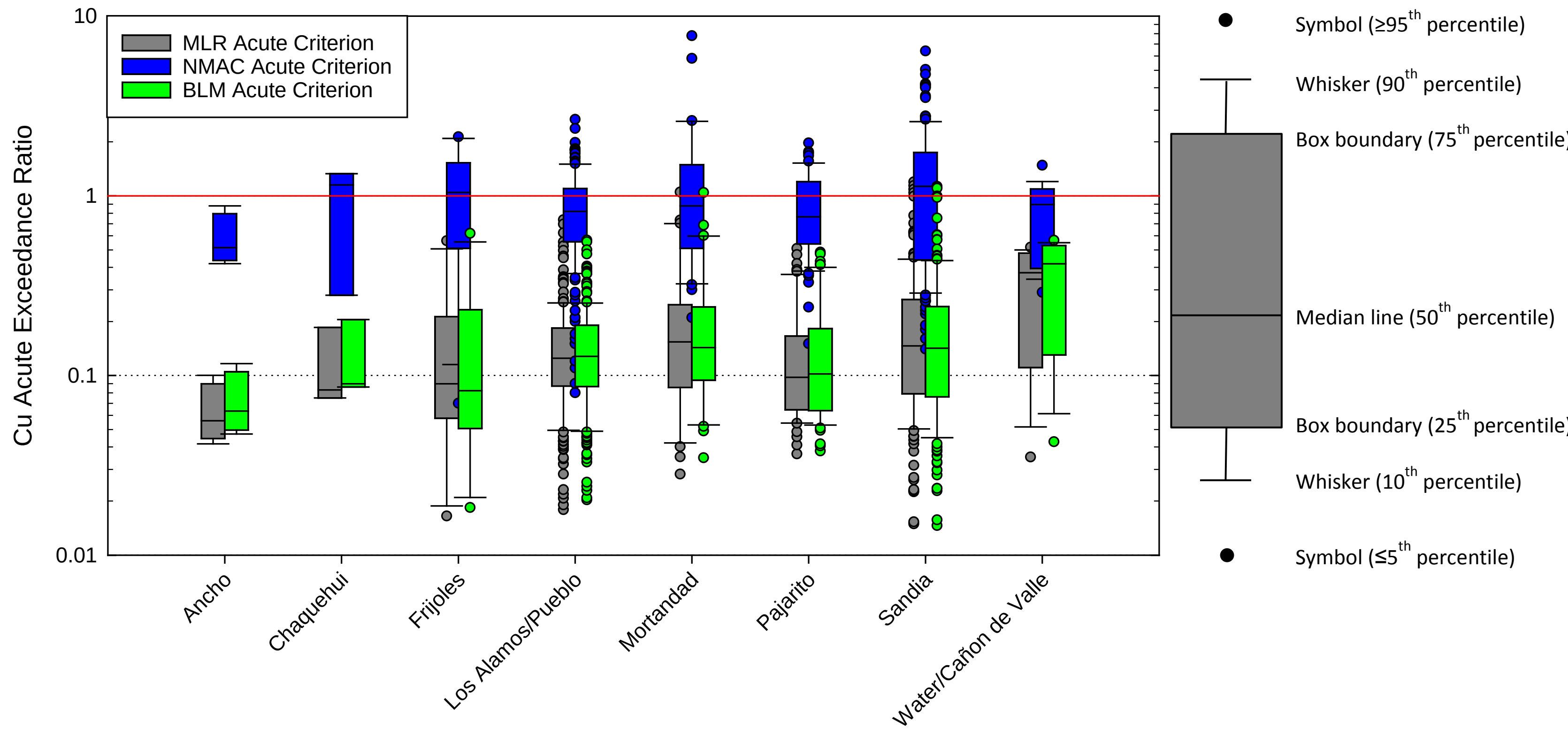


Figure 5-9. Acute copper exceedance ratios for EPA (2007) BLM, site-specific MLR, and New Mexico hardness-based WQC for major watersheds on the Pajarito Plateau

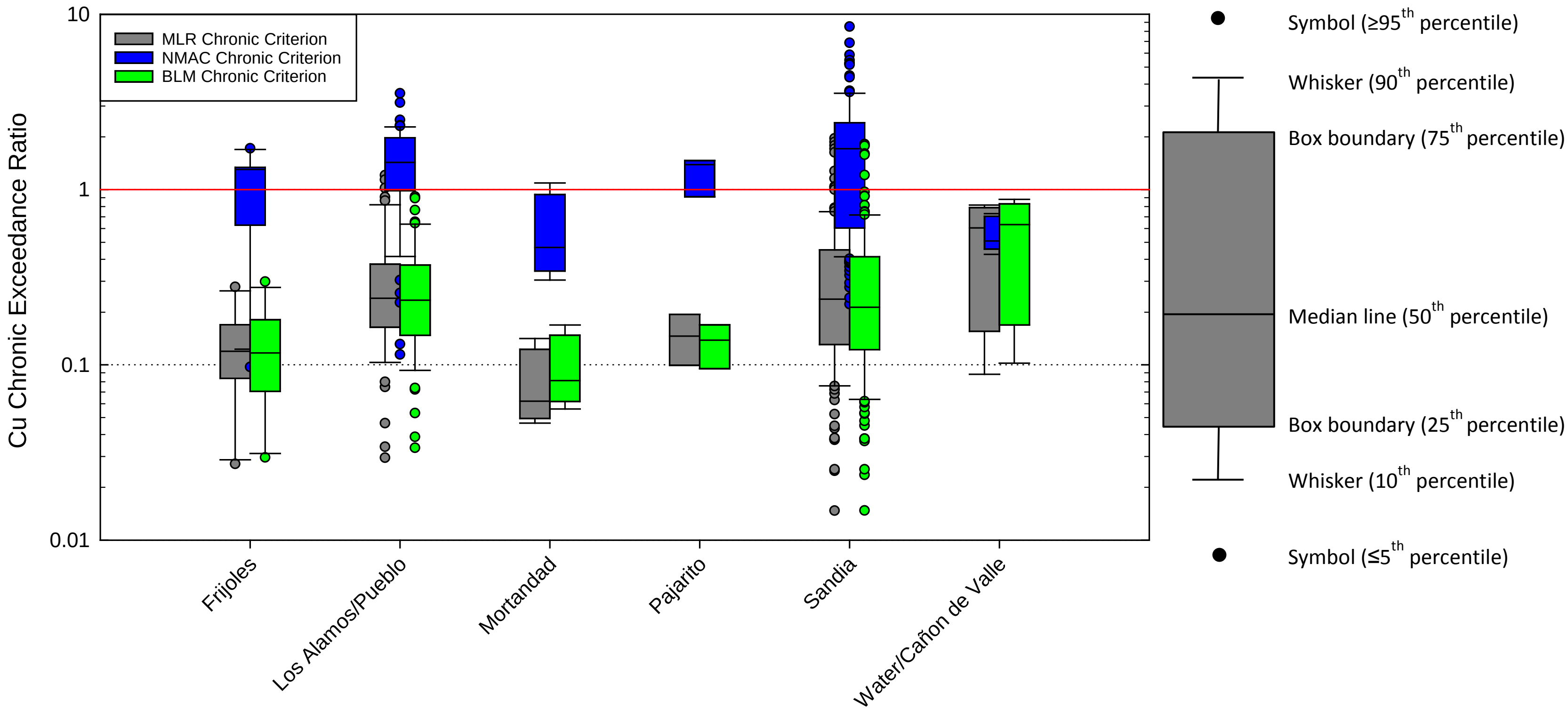


Figure 5-10. Chronic copper exceedance ratios for EPA (2007) BLM, site-specific MLR, and New Mexico hardness-based WQC for major watersheds on the Pajarito Plateau

Several conclusions can be drawn based on these comparisons. First, the frequency and magnitude with which copper concentrations exceed either BLM- or MLR-based acute WQC are very similar. For example, four exceedances of the acute BLM WQC and six exceedances of the acute MLR WQC and six exceedances of the chronic BLM WQC and 10 exceedances of the chronic MLR WQC were observed in the final DQO dataset (i.e., points above the horizontal dashed line or right of the vertical dashed line, respectively, in Figure 5-7).[19] The magnitude of these exceedances was low (i.e., acute exceedance ratios < 1.2 and chronic exceedance ratios < 2.0 for both models). Figure 5-7 also shows that exceedance ratios are highly correlated and distributed evenly around the solid diagonal 1:1 line (representing perfect agreement), again reflecting the high accuracy with which the MLR equations generate BLM software-based criteria.

Differences in exceedance frequencies between hardness-based WQC and BLM- or MLR-based WQC were substantial (e.g., n = 175 points to the right of the vertical dashed lines in Figure 5-8a and n = 131 points to the right of the vertical dashed lines in Figure 5-8b). Spatially, these hardness-based WQC exceedances occurred across most of the major Pajarito Plateau watersheds (Figure 5-9).

Finally, the differences observed between the hardness-based exceedance ratios and those calculated using either the BLM or MLR reflect the strong influence of water chemistry parameters other than hardness (e.g., pH and DOC) on the bioavailability and toxicity of copper. Consequently, continued application of the current hardness-based copper WQC is likely to lead to inaccurate and unnecessary regulatory actions (e.g., 303[d] listings and TMDLs), given that the MLR-based copper WQC are based on the best available science and provide a more accurate level of protection in accordance with EPA (1985, 2007a) recommendations.

5.6 Consideration of Downstream Rio Grande Waters

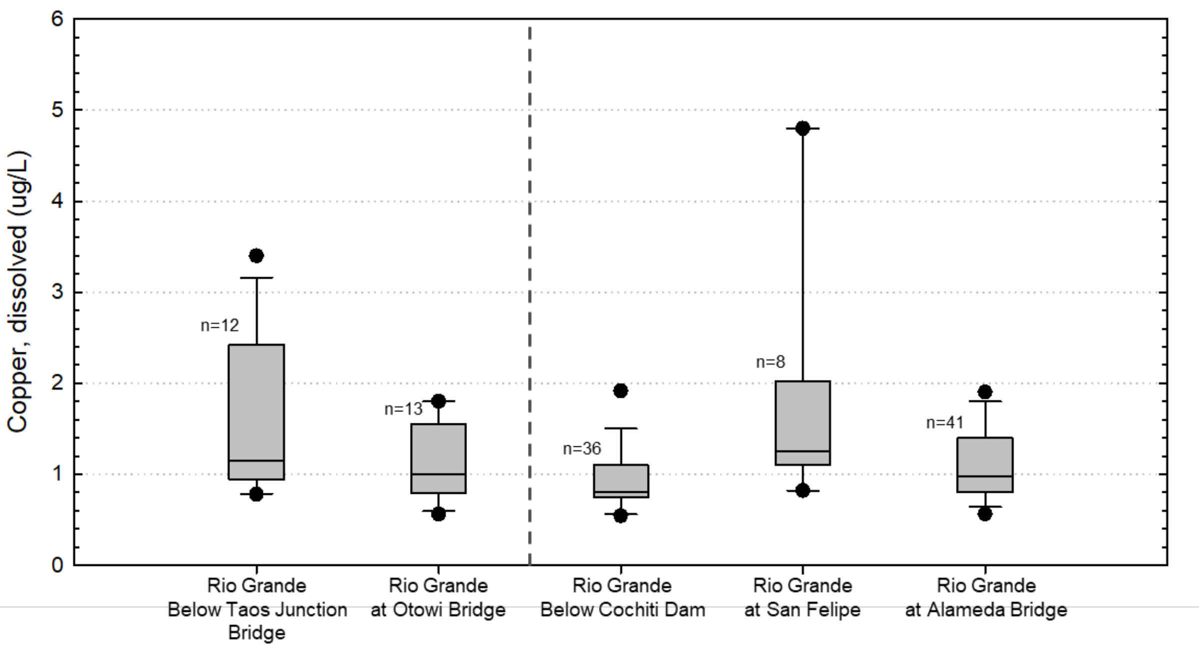
The SSWQC proposed in this report would apply to waters flowing into the Rio Grande from the Pajarito Plateau but not to waters of the Rio Grande. Potential impacts of the SSWQC on downstream waters in the Rio Grande were evaluated and found to be absent.

Rio Grande water quality data collected by the United States Geological Survey (USGS) were obtained from the National Water Quality Monitoring Council (2019) and were then input into the copper SSWQC equations and New Mexico's hardness-based copper criteria equations. Figure 5-11 shows available copper concentrations measured at USGS gaging stations on the Rio Grande from 2005 to 2021.[20] Copper concentrations in the Rio Grande upstream and downstream of confluences with

[19] Figures 5-7 to 5-9 exclude samples with non-detect copper concentrations exceeding the BLM copper WQC.

[20] Rio Grande data used for this evaluation are also presented in Appendix D (Table D-1).

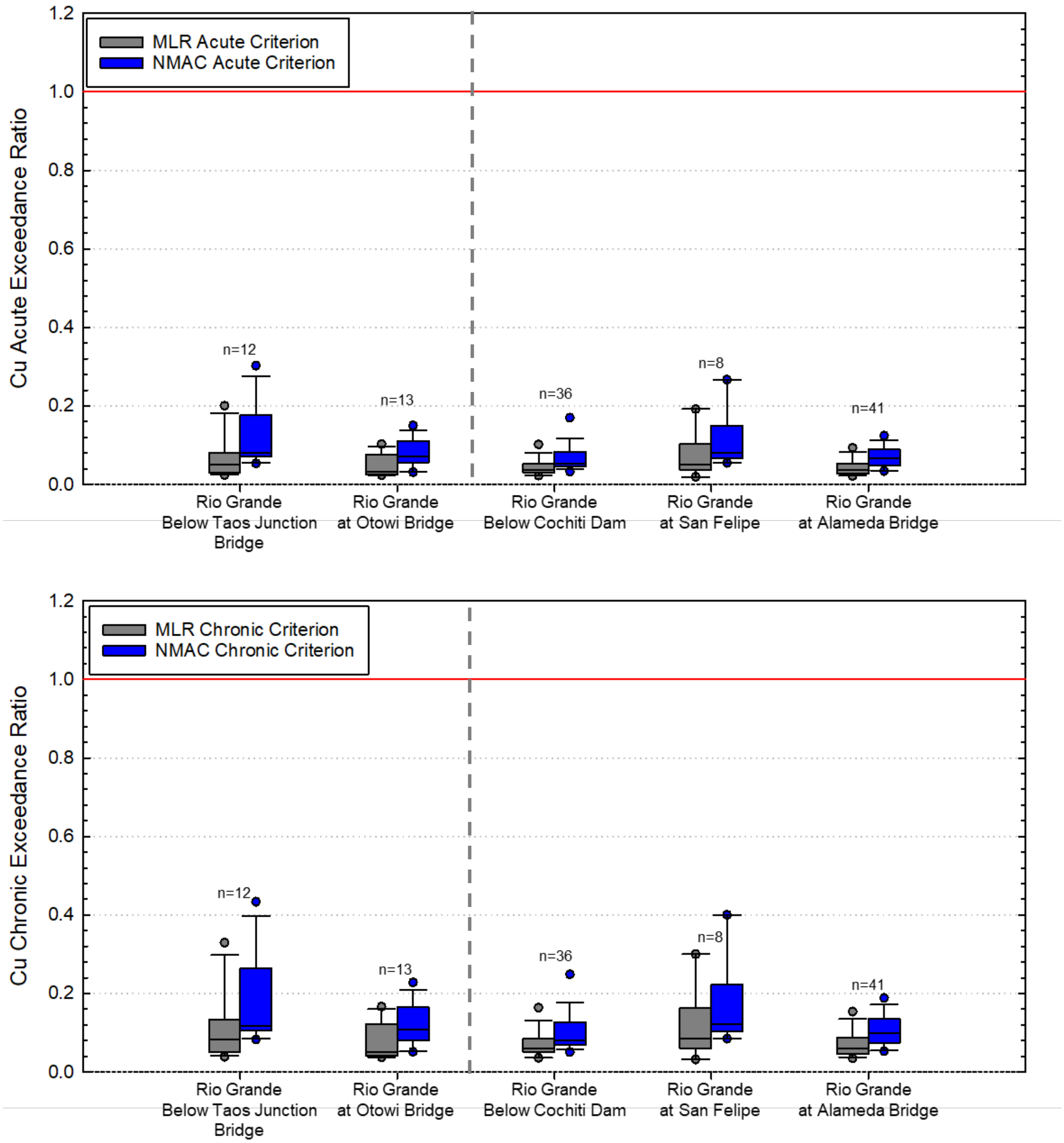
Pajarito Plateau tributaries are low and stable, and no samples contained copper concentrations in excess of either the hardness-based criteria or the BLM-based SSWQC (Figure 5-12). This finding is also consistent with the lack of 303(d) listings for copper in the Rio Grande in the vicinity (upstream and downstream) of the Laboratory. The two AUs of the Rio Grande above and three AUs below confluences with Pajarito Plateau tributaries have not been listed as impaired due to copper in New Mexico's 303(d)/305(b) IRs available on NMED's webpage (NMED 2021), which includes listings for the 2008-2010 IR through the draft 2022-2024 IR cycles. It is also notable that copper concentrations in the Rio Grande are comparable to or less than copper background threshold values (BTVs) derived for undeveloped conditions on the Pajarito Plateau (3.12 µg/L) and substantially less than BTVs for developed conditions (urban runoff) unrelated to LANL (9.03 µg/L) (Windward 2020).



Source: National Water Quality Monitoring Council (2019)

Note: The vertical dashed line indicates the division between locations that are upstream of confluences draining from the Pajarito Plateau (left of line) and those that are downstream (right of line).

Figure 5-11. Dissolved copper concentrations in Rio Grande surface water



Note: The vertical dashed line indicates the division between locations that are upstream of confluences draining from the Pajarito Plateau (left of line) and those that are downstream (right of line). The red line is the threshold above which copper exceeds the associated criterion.

Figure 5-12. Copper WQC exceedance ratios for Rio Grande surface waters

As discussed in Section 2.2, the proposed copper SSWQC do not entail new activities, such as new discharges or sources of copper, that could potentially lead to an increase in copper loads to the Rio Grande. In addition, surface flows from the Pajarito Plateau rarely reach the Rio Grande due to limited flow durations and infiltration in the canyon reaches upgradient of the Rio Grande (Section 3.3). Based on these considerations, adoption of the SSWQC is expected to remain protective of aquatic life uses in the Rio Grande.

6 Conclusions and Recommended Copper SSWQC

Over the past 40 years, the scientific understanding of metal toxicity and bioavailability to aquatic organisms and the corresponding environmental regulations have increased. EPA has revised nationally recommended copper WQC from a simple linear equation based on hardness to a mechanistic model (the copper BLM) that more accurately accounts for the modifying effect of site-specific water chemistry. Accordingly, BLM inputs and outputs were used to develop MLR equations proposed as copper SSWQC for surface waters of the Pajarito Plateau.

Streams on the Pajarito Plateau are thoroughly monitored under a variety of EPA and NMED programs, so it is a suitable setting for developing BLM-based WQC. Using a site-specific dataset generated from long-term monitoring, the current evaluation demonstrates that pH, DOC, and hardness concentrations account for 98% of the variation in BLM WQC. Therefore, the copper BLM can be estimated using a three-parameter MLR equation without losing significant accuracy, and while retaining the scientific rigor afforded by the BLM.

Given the high degree of agreement between the acute and chronic MLRs and the BLM, the equations presented in Section 6.1 can be adopted as copper SSWQC. They will provide accurate criteria that are protective of aquatic life in surface waters of the Pajarito Plateau, consistent with EPA recommendations and New Mexico WQS (20.6.4.10 NMAC).

6.1 Proposed Copper SSWQC Equations and Applicability

MLR equations were developed for both acute and chronic copper SSWQC for application to surface waters of the Pajarito Plateau. The use of one or both of the SSWQC depends on the hydrologic classification of the waterbody, as described below.

The proposed acute SSWQC is as follows:

$$\boldsymbol{SSWQC_{acute} = exp(-22.914 + 1.017 \times ln(DOC) + 0.045 \times ln(hardness) + 5.176 \times pH - 0.261 \times pH^2)}$$

The proposed chronic SSWQC is as follows:

$$\boldsymbol{SSWQC_{chronic} = exp(-23.391 + 1.017 \times ln(DOC) + 0.045 \times ln(hardness) + 5.176 \times pH - 0.261 \times pH^2)}$$

As described in Section 3.3, the Pajarito Plateau has ephemeral, intermittent, and perennial surface waters. Hydrologic classifications did not influence the ability of the proposed acute and chronic SSWQC to accurately estimate BLM calculations. Therefore, the acute and chronic copper SSWQC equations can be applied to any water body on the Pajarito Plateau.

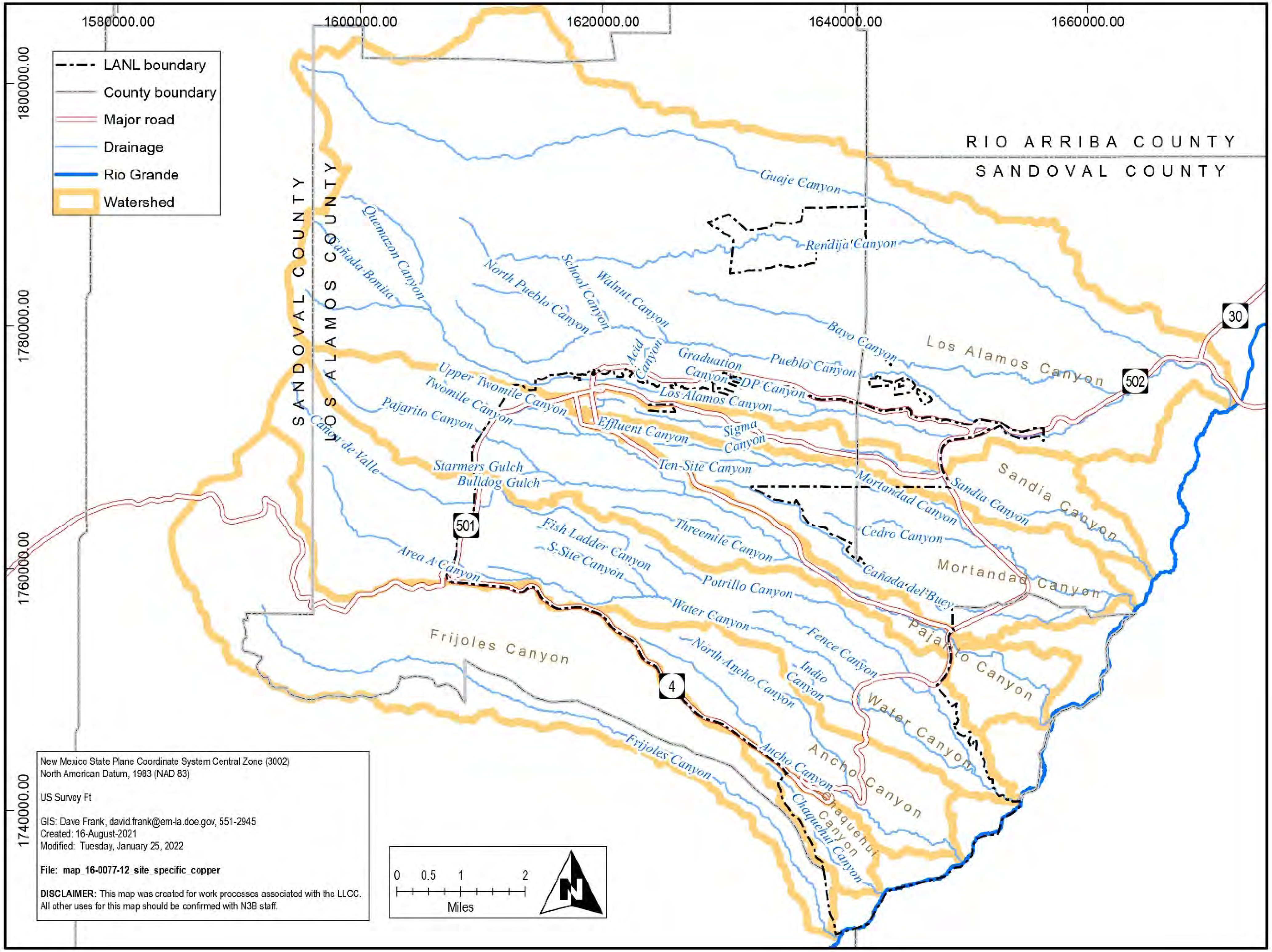
Most water bodies within the Laboratory's vicinity are classified as ephemeral or intermittent (20.6.4.128 NMAC); they are therefore designated as providing a limited aquatic life use and are subject to acute WQC only. Thus, the acute SSWQC equation would apply to those waters.

Other water bodies in the area are classified as perennial (20.6.4.126 and 20.6.4.121 NMAC) and are designated as providing higher-level aquatic life uses; these water bodies are subject to both acute and chronic aquatic life WQC. Unclassified surface water segments (20.6.4.98 NMAC) are designated as providing a marginal warm water aquatic life use and are subject to both acute and chronic WQC. Both the acute and chronic equations would apply to perennial and unclassified waters of the Pajarito Plateau.

As discussed in Section 2.4, the copper SSWQC are intended for eventual use in NPDES permits applicable to surface waters of the Pajarito Plateau. If the proposed copper SSWQC are adopted into New Mexico's WQS, updated TALs, benchmarks, and water quality-based effluent limits would be developed in accordance with each permitting program using the SSWQC criteria equations and appropriate datasets.

6.2 SPATIAL BOUNDARIES FOR PROPOSED SSWQC

The spatial boundaries for the proposed SSWQC include all watersheds within the area of the Pajarito Plateau, from the Guaje Canyon watershed in the north to El Rito de Frijoles watershed in the south, from their headwaters to their confluence with the Rio Grande (Map 6-1). This area includes tributary streams and ephemeral or intermittent waters, regardless of whether they have a direct confluence with the Rio Grande or sufficient flow to reach the Rio Grande under normal conditions. Table 6-1 presents all AUs included in this area, their current classifications under NMAC, and their associated designated uses. The applicability of the acute and chronic SSWQC are also provided.



Map 6-1. Spatial boundary for proposed copper SSWQC

Table 6-1. Pajarito Plateau AUs Where SSWQC Would Apply

AU ID	Major Watershed	AU Name	Stream Type	NMAC Class	SSWQC Applicability	Designated Use*						
						AL	Irr.	LW	WH	DW	PC	SC
NM-9000.A_054	Ancho	Ancho Canyon (Rio Grande to North Fork Ancho)	ephemeral	128	acute only	X		X	X			X
NM-9000.A_055	Ancho	North Fork Ancho Canyon (Ancho Canyon to headwaters)	ephemeral	128	acute only	X		X	X			X
NM-9000.A_046	Chaquehui	Ancho Canyon (North Fork to headwaters)	ephemeral	128	acute only	X		X	X			X
NM-128.A_03	Chaquehui	Chaquehui Canyon (within LANL)	ephemeral	128	acute only	X		X	X			X
NM-9000.A_005	Chupaderos	Guaje Canyon (San Ildefonso bnd to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-2118.A_70	Frijoles	Rito de los Frijoles (Rio Grande to headwaters)	perennial	121	acute and chronic	X	X	X	X	X	X	
NM-126.A_03	Frijoles	Water Canyon (Area-A Canyon to NM 501)	perennial	126	acute and chronic	X	X	X	X			X
NM-97.A_002	Los Alamos/Pueblo	Acid Canyon (Pueblo Canyon to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-97.A_007	Los Alamos/Pueblo	Bayo Canyon (San Ildefonso bnd to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-128.A_14	Los Alamos/Pueblo	DP Canyon (Grade control to upper LANL bnd)	ephemeral	128	acute only	X		X	X			X
NM-128.A_10	Los Alamos/Pueblo	DP Canyon (Los Alamos Canyon to grade control)	intermittent	128	acute only	X		X	X			X
NM-97.A_005	Los Alamos/Pueblo	Graduation Canyon (Pueblo Canyon to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-97.A_003	Los Alamos/Pueblo	Kwage Canyon (Pueblo Canyon to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-9000.A_063	Los Alamos/Pueblo	Los Alamos Canyon (DP Canyon to upper LANL bnd)	ephemeral	128	acute only	X		X	X			X
NM-127.A_00	Los Alamos/Pueblo	Los Alamos Canyon (Los Alamos Rsvr to headwaters)	perennial	127	acute and chronic	X	X	X	X		X	
NM-9000.A_006	Los Alamos/Pueblo	Los Alamos Canyon (NM-4 to DP Canyon)	ephemeral	128	acute only	X		X	X			X
NM-9000.A_000	Los Alamos/Pueblo	Los Alamos Canyon (San Ildefonso bnd to NM-4)	intermittent	98	acute and chronic	X		X	X		X	
NM-9000.A_049	Los Alamos/Pueblo	Los Alamos Canyon (upper LANL bnd to Los Alamos Rsvr)	ephemeral	98	acute and chronic	X		X	X		X	

AU ID	Major Watershed	AU Name	Stream Type	NMAC Class	Designated Use*							
					SSWQC Applicability	AL	Irr.	LW	WH	DW	PC	SC
NM-9000.A_043	Los Alamos/Pueblo	Pueblo Canyon (Acid Canyon to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-99.A_001	Los Alamos/Pueblo	Pueblo Canyon (Los Alamos Canyon to Los Alamos WWTP)	ephemeral	98	acute and chronic	X		X	X		X	
NM-97.A_006	Los Alamos/Pueblo	Pueblo Canyon (Los Alamos WWTP to Acid Canyon)	ephemeral	98	acute and chronic	X		X	X		X	
NM-9000.A_045	Los Alamos/Pueblo	Rendija Canyon (Guaje Canyon to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-97.A_029	Los Alamos/Pueblo	South Fork Acid Canyon (Acid Canyon to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-97.A_004	Los Alamos/Pueblo	Walnut Canyon (Pueblo Canyon to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-128.A_00	Mortandad	Canada del Buey (within LANL)	ephemeral	128	acute only	X		X	X			X
NM-128.A_17	Mortandad	Ten Site Canyon (Mortandad Canyon to headwaters)	ephemeral	128	acute only	X		X	X			X
NM-128.A_16	Pajarito	Arroyo de la Delfe (Pajarito Canyon to headwaters)	ephemeral	128	acute only	X		X	X			X
NM-126.A_01	Pajarito	Pajarito Canyon (Arroyo de La Delfe to Starmers Spring)	perennial	126	acute and chronic	X	X	X	X			X
NM-128.A_08	Pajarito	Pajarito Canyon (lower LANL bnd to Two Mile Canyon)	ephemeral	128	acute only	X		X	X			X
NM-9000.A_040	Pajarito	Pajarito Canyon (Rio Grande to LANL bnd)	ephemeral	98	acute and chronic	X		X	X		X	
NM-128.A_06	Pajarito	Pajarito Canyon (Two Mile Canyon to Arroyo de La Delfe)	intermittent	128	acute only	X		X	X			X
NM-9000.A_048	Pajarito	Pajarito Canyon (upper LANL bnd to headwaters)	intermittent	98	acute and chronic	X		X	X		X	
NM-128.A_07	Pajarito	Pajarito Canyon (within LANL above Starmers Gulch)	intermittent	128	acute only	X		X	X			X
NM-9000.A_091	Pajarito	Three Mile Canyon (Pajarito Canyon to headwaters)	ephemeral	128	acute only	X		X	X			X
NM-128.A_15	Pajarito	Two Mile Canyon (Pajarito to headwaters)	ephemeral	128	acute only	X		X	X			X
NM-9000.A_053	Rio Grande	Cañada del Buey (San Ildefonso Pueblo to LANL bnd)	ephemeral	98	acute and chronic	X		X	X		X	
NM-9000.A_042	Sandia	Mortandad Canyon (within LANL)	ephemeral	128	acute only	X		X	X			X

					Designated Use*							
AU ID	Major Watershed	AU Name	Stream Type	NMAC Class	SSWQC Applicability	AL	Irr.	LW	WH	DW	PC	SC
NM-9000.A_047	Sandia	Sandia Canyon (Sigma Canyon to NPDES outfall 001)	perennial	126	acute and chronic	X	X	X	X			X
NM-128.A_11	Sandia	Sandia Canyon (within LANL below Sigma Canyon)	ephemeral	128	acute only	X		X	X			X
NM-128.A_01	Water/Cañon de Valle	Canon de Valle (below LANL gage E256)	ephemeral	128	acute only	X		X	X			X
NM-126.A_00	Water/Cañon de Valle	Canon de Valle (LANL gage E256 to Burning Ground Spr)	perennial	126	acute and chronic	X	X	X	X			X
NM-9000.A_051	Water/Cañon de Valle	Canon de Valle (upper LANL bnd to headwaters)	intermittent	98	acute and chronic	X		X	X		X	
NM-128.A_02	Water/Cañon de Valle	Canon de Valle (within LANL above Burning Ground Spr)	ephemeral	128	acute only	X		X	X			X
NM-128.A_04	Water/Cañon de Valle	Fence Canyon (above Potrillo Canyon)	ephemeral	128	acute only	X		X	X			X
NM-128.A_05	Water/Cañon de Valle	Indio Canyon (above Water Canyon)	ephemeral	128	acute only	X		X	X			X
NM-128.A_09	Water/Cañon de Valle	Potrillo Canyon (above Water Canyon)	ephemeral	128	acute only	X		X	X			X
NM-9000.A_044	Water/Cañon de Valle	Water Canyon (Rio Grande to lower LANL bnd)	ephemeral	98	acute and chronic	X		X	X		X	
NM-9000.A_052	Water/Cañon de Valle	Water Canyon (upper LANL bnd to headwaters)	intermittent	98	acute and chronic	X		X	X		X	
NM-128.A_12	Water/Cañon de Valle	Water Canyon (within LANL above NM 501)	intermittent	128	acute only	X		X	X			X
NM-128.A_13	Water/Cañon de Valle	Water Canyon (within LANL below Area-A Cyn)	ephemeral	128	acute only	X		X	X			X

* AL – aquatic life; Irr. – irrigation; LW – livestock watering; WH – wildlife habitat; DW – drinking water; PC – primary contact; SC – secondary contact

AU – assessment unit

ID – identification

NMAC – New Mexico Administrative Code

SSWQC – site-specific water quality criteria

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EXHIBIT B

From:	Amanda B. White <Amanda.White@em-la.doe.gov>
Sent:	Wednesday, July 28, 2021 5:45 PM
To:	DiazLopez.Jasmins@epa.gov; nelson.russell@epa.gov; Fullam, Jennifer, NMENV; wooster.richard@epa.gov; shelly.lemon@state.nm.us; kristopher.barrios@state.nm.us
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Subject:	Copper Site-Specific Water Quality Criteria for the Pajarito Plateau: Demonstration Report
Attachments:	Response to NMED Comments on the Copper SSWQC Work Plan.xlsx; Draft Final Cu SSWQC Demonstration Report+Appendices_072821.pdf

Hello,

Attached is the draft final "Copper Site-Specific Water Quality Criteria for the Pajarito Plateau: Demonstration Report" and our responses to NMED and EPA's comments on the "Copper Site-Specific Water Quality Criteria for the Pajarito Plateau: Work Plan." We would sincerely appreciate your comments as soon as practicable.

Thank you,

Amanda White, Ph.D.
Program Manager / Watershed Monitoring and Technical Services
Mobile: 505.309.1366
critical subcontractor to **N3B ER Water Program**

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Via Email

November 9, 2021

Amanda White
Program Manager
Watershed Monitoring and Technical Services
Tech2 Solutions
Via email to Amanda.white@em-la.doe.gov

Re: Request for Additional Information for the Pajarito Plateau Site-Specific Water Quality Copper Criteria Demonstration

Dear Amanda White,

On July 28, 2021, the New Mexico Environment Department ("Department" or "NMED") Surface Water Quality Bureau ("SWQB") received a "draft final" Demonstration Report for Copper Site-Specific Criteria for Surface Waters on the Pajarito Plateau ("Demonstration"). This Demonstration was prepared by Windward Environmental on behalf of Newport News Nuclear BWXT Los Alamos ("N3B"), the contractor currently responsible for managing the Los Alamos National Laboratory ("LANL") legacy cleanup contract for the U.S. Department of Energy ("DOE").[1] The Department notes that site-specific numeric criteria are relevant and justified when *site-specific conditions* in a watershed or specific surface water warrant a different criterion (*see* 20.6.4.10(D)(1) NMAC for a list of potential conditions).

The Department and the U.S. Environmental Protection Agency ("EPA") Region 6 reviewed the Demonstration but need additional information to provide further technical review. If N3B would like the Department to provide further technical review, please submit a revised site-specific demonstration that includes the additional required elements and clarifications noted below:

- Based on the findings of the Demonstration and pursuant to 20.1.6.200 NMAC, N3B must include the amended language of 20.6.4 NMAC as it will be proposed to the Water Quality Control Commission.
- N3B must list the surface waters of the state to which the Demonstration applies, in accordance with 20.6.4.10(D)(3)(a) NMAC, including the applicable assessment unit, current designated uses, and any applicable site-specific criteria.
- N3B must show that the site-specific criteria will not be in conflict with the State's antidegradation policy protections for existing uses, in accordance with 20.6.4.8 NMAC. N3B should provide a list of existing uses for each tributary and how these existing uses were derived, particularly as they pertain to copper, as supporting evidence.
- Consistent with 20.6.4.10(D)(1) NMAC, N3B must provide the relevant site-specific condition(s) that warrant site-specific criteria and why these criteria would not be applicable to adopt as a state-wide numeric criteria. N3B should consider why the multiple linear regression ("MLR") translation of the biotic ligand model ("BLM") is appropriate for this Demonstration as opposed to a broad, state-wide application.
- Consistent with 20.6.4.10(D)(2) NMAC, N3B must provide evidence in the Demonstration that the site-specific criteria fully protect the applicable designated uses and are therefore still protective of downstream uses, in accordance with 40 C.F.R. 131.10(b).
- N3B should expand Section 2.1.1 regarding relevant conditions for developing site-specific surface water

[1] https://n3b-la.com/

quality criteria to describe the physical and chemical characteristics of the site affecting the bioavailability and toxicity of copper. N3B should also explain how, even though these conditions exist, the proposed criteria will fully protect designated uses and downstream waters.

- N3B should discuss current National Pollutant Discharge Elimination System ("NPDES") Individual Permit ("IP") target action levels, multi-sector general permit ("MSGP") benchmarks, and water quality-based effluent limits ("WQBELs") for copper applicable to LANL's NPDES discharges, and any reported exceedances.
- In Section 3.4.1, regarding sampling, N3B identifies sampling for all BLM parameters. However, from the information provided in Section 1.1 of the Demonstration, N3B is only evaluating pH, Dissolved Organic Carbon ("DOC") and hardness. For clarification, in Section 3.4.1 of the Demonstration, N3B should include the parameters sampled, particularly if not all ten of the parameters are included in a BLM.
- Because some of the BLM input parameters are known to vary seasonally, N3B should provide at least one sampling event per season. To show this, N3B should include a distribution of sampling frequency for each month.
- N3B should include a table with sampling locations, their relative assessment units, and designated uses.
- There was insufficient information regarding the sampling schedule and quality assurance for the sampling events to evaluate the Demonstration effectively. This includes explaining how data were validated and verified and determined to be scientifically defensible, as well as custody sheets, holding times, sampling methodology (i.e. grab or 24-hour composite), sources of sample (i.e. baseflow, effluent, stormflow, combination) and the occurrence of precipitation events that would influence the flow, offsetting baseflow conditions. Until this information is provided in the Demonstration the Department and EPA are unable to evaluate the technical merit of the Demonstration effectively.
- N3B should provide the findings of steps one through seven in Section 5.1 regarding Data Quality Objectives ("DQOs") and Data Quality Assurances ("DQAs") prior to discussing the outcome of the process. Discussion should include the performance and acceptance criteria for the data and the frequency of the data that was determined acceptable.
- Section 5 should include figures comparing chronic exceedance ratios in addition to acute.
- In Section 6, regarding conclusions and recommended criteria, N3B concludes with chronic and acute equations for waters on the Pajarito Plateau; however, N3B did not adequately demonstrate the need for site-specific criteria nor the applicability of the chronic and acute equations to site-specific waters on the Pajarito Plateau.
- N3B should add a table comparing the current hardness based acute and chronic criteria for each of the proposed site-specific waters to the acute and chronic criteria calculated using the modified BLM equations to demonstrate the criteria are protective of designated uses and downstream waters.
- N3B should include a summary table and discussion of a sensitivity analysis supporting why only pH, hardness, and DOC are relevant for an MLR translation.

If you have any questions regarding these comments or the process, please contact Jennifer Fullam by email at jennifer.fullam@state.nm.us or by phone at 505.946.8954.

Sincerely,

Shelly Lemon, Chief
Surface Water Quality Bureau

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Date: August 24, 2023
Refer To: N3B-2023-0231

Shelly Lemon, Chief
Surface Water Quality Bureau
New Mexico Environment Department
1190 St. Francis Drive
Santa Fe, NM 87502-5469

Subject: Response to New Mexico Environment Department and U.S. Environmental Protection Agency Comments on Pajarito Plateau Site-Specific Water Quality Copper Criteria Demonstration and Copper Site-Specific Water Quality Criteria for the Pajarito Plateau: Demonstration Report

Dear Ms. Lemon:

On March 31, 2023, the U.S. Department of Energy Environmental Management Los Alamos Field Office (EM-LA) and Newport News Nuclear BWXT-Los Alamos, LLC (N3B) received comments from the New Mexico Environment Department (NMED) Surface Water Quality Bureau and the U.S. Environmental Protection Agency (EPA) on the "Pajarito Plateau Site-Specific Water Quality Copper Criteria Demonstration" (hereafter, Demonstration Report).

On July 28, 2021, EM-LA and N3B provided a draft Demonstration Report to NMED and EPA. On November 9, 2021, NMED and EPA provided comments and requested additional information. In response, EM-LA and N3B provided to NMED and EPA a revised draft version of the Demonstration Report on March 30, 2022; comment responses on April 18, 2022; and additional materials on May 31, 2022.

EM-LA/N3B appreciate NMED and EPA's review and comments on the Demonstration Report, as well as the follow-up technical discussion, which occurred in person and via teleconference on June 29, 2023. EM-LA/N3B are pleased to provide the enclosed response to NMED's request for additional information and comments (Enclosure 1). Also enclosed is a revised Demonstration Report that addresses the elements and clarifications requested by NMED (Enclosure 2).

If you have questions, please contact Amanda White at (505) 309-1366 (amanda.white@em-la.doe.gov) or Cheryl Rodriguez at (505) 414-0450 (cheryl.rodriguez@em.doe.gov).

Sincerely,

Troy Thomson
Program Manager
Environmental Remediation
N3B-Los Alamos

Sincerely,

ARTURO DURAN Digitally signed by ARTURO DURAN
Date: 2023.08.23 15:36:37 -06'00'

Arturo Q. Duran
Compliance and Permitting Manager
Office of Quality and Regulatory Compliance
U.S. Department of Energy
Environmental Management
Los Alamos Field Office

Enclosure(s):

1. Response to New Mexico Environment Department and U.S. Environmental Protection Agency Comments on Pajarito Plateau Site-Specific Water Quality Copper Criteria Demonstration, Dated March 31, 2023
2. Copper Site-Specific Water Quality Criteria for the Pajarito Plateau: Demonstration Report, Final

cc (letter and enclosure[s] emailed):
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ENCLOSURE 1

Response to New Mexico Environment Department and U.S. Environmental Protection Agency Comments on Pajarito Plateau Site-Specific Water Quality Copper Criteria Demonstration

Response to New Mexico Environment Department and U.S. Environmental Protection Agency Comments on Pajarito Plateau Site-Specific Water Quality Copper Criteria Demonstration, Dated March 31, 2023

INTRODUCTION

To facilitate review of this response, the New Mexico Environment Department's (NMED's) and U.S. Environmental Protection Agency's (EPA's) comments are included verbatim. The U.S. Department of Energy (DOE) Environmental Management Los Alamos Field Office responses follow each NMED and EPA comment.

NMED GENERAL COMMENTS AND ACKNOWLEDGEMENTS

NMED Comment

1. In Section 2.4, the Department appreciates N3B's expanded discussion on the current National Pollutant Discharge Elimination System ("NPDES") Individual Permit ("IP") target action levels, multi- sector general permit ("MSGP") benchmarks, and water quality-based effluent limits ("WQBELs") for copper applicable to LANL's NPDES discharges, and any reported exceedances.

DOE Response

1. Comment acknowledged; thank you.

NMED Comment

2. In Section 3.4.1, the Department appreciates the additional information provided regarding sampling and how the Biotic Ligand Model ("BLM") input values were determined. Additionally, the Department appreciates the explanation of how a combination of estimated and default values were used in the BLM, rather than using direct measurements.

DOE Response

2. Comments acknowledged; thank you.

NMED Comment

3. In Section 3.4.1, the Department appreciates the expanded explanation regarding sampling.

DOE Response

3. Comment acknowledged; thank you.

NMED Comment

4. In Section 5.4.2, the Department appreciates N3B's inclusion of figures comparing chronic exceedance ratios in addition to acute.

DOE Response

4. Comment acknowledged; thank you.

NMED Comment

5. In Section 5.5, the Department appreciates the additional information provided by N3B comparing the current hardness-based acute and chronic criteria that provides some insight on the percentage of sampled waters that may have criteria less stringent than the current hardness-based criteria.

DOE Response

5. Comment acknowledged; thank you.

NMED Comment

6. In Section 5.3, the Department appreciates that additional information in Table 5-3 and discussion of sensitivity. The Department recommends expanding further on the exclusion of potassium given the positive correlation with the model outputs.

DOE Response

6. Comment acknowledged; thank you. A brief discussion of potassium has been included in section 5.3 to explain why it was not ultimately included in the multiple linear regressions (MLRs).

NMED Comment

7. In Section 5.1, the Department appreciates the inclusion of a table with sampling locations. The Department requests that this table provide latitude and longitude in decimal degrees rather than what appears to be National Marine Electronics Association ("NMEA") Global Positioning System ("GPS") Units, which must be converted manually to useable coordinates.

DOE Response

7. Although section 5.1 does not provide coordinates for individual sampling locations, the coordinates are included in Appendix A. The X/Y coordinates were reported using the North America Datum of 1983 (NAD83) New Mexico State Plane Central system (in U.S. ft), which is how coordinates are stored in the Los Alamos National Laboratory's (LANL's) Intellus and EIM (Environmental Information Management) databases. This has been clarified in the table heading of Appendix A.

NMED Comment

8. In Section 5.1, the Department appreciates the additions regarding Data Quality Objectives and Data Quality Assurances.

DOE Response

8. Comment acknowledged; thank you.

NMED Comment

9. ***In Section 6.2 and Appendix A, the Department appreciates the inclusion of N3B's proposed language in 20.6.4 NMAC and list of surface waters and designated uses. However, the Department requests the table in Appendix A, as well as narrative portions in the Demonstration, reflect the current references to 20.6.4 NMAC (effective date 09.24.2022).***

DOE Response

9. References to 20.6.4 New Mexico Administrative Code (NMAC) have been updated, as requested.

NMED Comment

10. ***In Appendix A, the Department appreciates the inclusion of the supporting data, which provides the extent of seasonality in the dataset used to develop the proposed copper criteria.***

DOE Response

10. Comment acknowledged; thank you.

NMED Comment

11. ***In Appendix C, Footnote 1 states that a draft work plan was provided to the Department on July 7, 2020; however, the Department was given an explicit request from N3B and Triad, during a meeting in July 2020, to refrain from reviewing until such a time that Triad had time to review and concur with the proposal. This permission was not provided to NMED until September 2020. Please change the date from July 7, 2020 to September 9, 2020.***

DOE Response

11. The noted date has been revised.

NMED Comment

12. ***In Table C1 of Appendix C, N3B states the responses to NMED and EPA's comments on the work plan and the final draft Demonstration were sent on June 11, 2021 and August 20, 2021, respectively. However, both documents were provided to NMED on July 28, 2021. N3B later sent a corrected Demonstration to NMED/EPA on August 20, 2021. Additionally, N3B's response to comments was dated April 18, 2022, not April 15, 2022, as provided in Table C1. The Department requests that N3B correct these dates referenced in Appendix C.***

DOE Response

12. The June 11, 2021, date has been revised to June 28, 2021. However, the August 20, 2021, date does not appear in Table C1. The date reported was already June 28, 2021; therefore, that date was not changed. The April 18, 2022, date is now reflected in the table. The table has otherwise been updated to be current, with approximate unfinished dates.

NMED Comment

13. EPA's 2007 BLM vs. MLR:

The Department urges N3B to clearly identify throughout the Demonstration that the proposed Site-Specific Water Quality Criteria ("SSWQC") are not simply based on EPA 304(a) criteria[2] [EPA. 2007. Recommended Aquatic Life Ambient Freshwater Quality Criteria for Copper using a Biotic Ligand Model ("BLM")]. The method described in the Demonstration is not EPA's BLM and therefore is not the approach referenced in 20.6.4.10(F)(4)(c) NMAC. N3B is proposing a multiple linear regression ("MLR") translation of EPA's BLM approach. The Department does not find any issue with an alternative method to derive copper criteria if it is defensible and based on scientific evidence.

The Demonstration begins with a simplified version of the BLM (not EPA recommended), includes stormwater data (vs. only ambient data as described in EPA's 2007 BLM), and derives copper criteria using a MLR (not a BLM). The Department recognizes that EPA is working towards MLR-derived criteria for some metals, including copper, but until these have been adopted as recommended CWA 304(a) criteria. Any proposed site-specific criteria using MLR requires an independent demonstration of defensibility based on scientific evidence. The continued iteration throughout the Demonstration that N3B is using EPA's 2007 BLM is a misrepresentation of the method and analysis.

DOE Response

13. While DOE and Newport News Nuclear BWXT-Los Alamos, LLC (N3B) agree that the MLR is not equivalent to EPA's 2007 biotic ligand model (BLM), the selected MLR approach is implicitly based on the BLM. Derivation of the MLRs involved running the site-specific dataset from the Pajarito Plateau through the BLM to generate BLM criteria. Then, MLR analysis identified three toxicity-modifying parameters that had the most significant effect on BLM criteria, explaining approximately 98% of the variance in BLM criteria over the ambient water chemistry range. Thus, the MLR equation uses pH, hardness, and dissolved organic carbon (DOC) to generate BLM-based criteria with a high degree of accuracy. Therefore, the magnitudes of the proposed criteria are inherently based on the EPA 2007 BLM, given that the criterion was the independent variable in the MLR approach.

    The demonstration begins with the full version of the BLM, which is the EPA recommended method. NMED is correct that the subsequent MLR derivation steps result in criteria that are not directly equivalent to the Clean Water Act (CWA) 304(a) criteria, but as noted above and shown in the "Demonstration Report for Copper Site-Specific Criteria for Surface Waters on the Pajarito Plateau" (hereafter, the Demonstration Report), the resulting criteria are highly comparable to the CWA 304(a) criteria (adjusted R^2 = 0.98). The text has been clarified throughout.

NMED Comment

14. Dissolved Organic Carbon ("DOC") and Total Organic Carbon ("TOC"):

The Department has found the Demonstration's references for estimating the percent humic acid from DOC satisfactory. The Department recognizes that EPA's 2007 BLM discusses that the conversion of TOC to DOC can be done using a conversion factor based on DOC:TOC ratio. In the Demonstration, N3B and Windward Environmental note that a total of 124 DOC values were estimated from available TOC data because DOC data were not collected during these sampling events.

However, the Department has concerns regarding data quality of the underlying TOC and DOC datasets and estimating DOC from available TOC data as described in the Demonstration. N3B and Windward Environmental note that "…more than one-half of the available data indicate that DOC exceeds TOC, which is conceptually impossible" (N3B response page, B-4). Therefore, N3B and Windward Environmental removed these data from the calculation of the DOC:TOC ratio and conversion factor, but did not remove these data from the entire MLR development process. The Department questions why these suspect DOC and TOC values were not rejected during the data verification and validation process and completely removed from all analyses related to this demonstration. N3B and Windward Environmental note that "[t]his appears to be a consistent analytical uncertainty" but do not provide any information from the analytical laboratory to support this statement. To fully address these DOC and TOC data quality concerns, the Department recommends using verified and validated DOC data only where DOC values are less than TOC values.

DOE Response

14. LANL total organic carbon (TOC) data are generated analytically by measuring carbon in an unfiltered sample, which differs from other DOC/TOC methods where TOC is calculated as the sum of DOC and particulate organic carbon (POC). While the latter method will never result in DOC values that exceed TOC values, the former method is consistent with how Los Alamos National Laboratory (LANL) measures other analytes in surface waters, including total metals, polychlorinated biphenyls. DOE's and N3B's effort to use LANL's existing TOC data to calculate a DOC:TOC ratio was intended to enhance the site-specificity of the MLR dataset. DOE and N3B took the conservative step of removing all samples where DOC exceeds TOC to account for analytical variability/uncertainty and minimize bias, and DOE and N3B confirmed that the calculated DOC:TOC ratio was reasonable by comparing it to literature-based values (e.g., EPA 2007). The selected method of limiting the DOC and TOC data to samples where DOC ≤ TOC resulted in a median DOC:TOC ratio of 0.86, which is virtually identical to EPA's nationwide average (0.857) from the Cu BLM guidance (EPA 2007). EPA's comment #4 cites its BLM guidance document as a reasonable source for a DOC:TOC ratio; thus, the ratio in the demonstration report is supported by the literature and EPA.

    With regard to removing data, DOE and N3B want to clarify that the DOC and TOC data were generated using LANL's standard sampling and analytical procedures, and data were subjected to normal quality assurance (QA)/quality control (QC) and validation. The DOC and TOC data were not flagged as problematic, and as such, they are high-quality data and should not be excluded. All analytical data are subject to some degree of uncertainty and variability regardless of the laboratory or parameter; this does not invalidate all chemistry data.

    To be responsive to NMED's comment, DOE has revised the discussion of DOC:TOC in the Demonstration Report to clarify and further substantiate the selected approach and resulting DOC:TOC value.

NMED Comment

15. Use of stormwater data to develop the criteria:

It is the Department's understanding that the EPA 2007 BLM guidance was primarily intended for use in perennial streams under stable conditions (i.e., equilibrium). Given 73% of the data used for the development of these site-specific criteria are from storm events, it is important to understand if the use of stormwater data in the models may skew the proposed criteria. N3B commented that, "EPA's BLM-based criteria apply regardless of flow conditions or hydrologic regimes." The Department *requests N3B include supporting evidence in the Demonstration to support the appropriateness of using stormwater data to develop the proposed criteria.*

DOE Response

15. The EPA 2007 BLM guidance reflects EPA's current national copper criteria, which is recommended for all types of hydrologic regimes and surface flows, including storm flows. The EPA 2007 copper criteria are designed for protection against both short-term (acute) and long-term (chronic) effects on freshwater aquatic life. Most studies that formed the basis of the copper BLM measured acute endpoints following aquatic life exposure to copper over short periods. The acute copper BLM criteria are appropriate for storm flows given the short-term (acute) exposures that occur during episodic storm flows, particularly in ephemeral and intermittent waters.

    In 2017, EPA funded a study conducted by the National Academies of Sciences (NAS) aimed at improving stormwater management under the Multi-Sector General Permit (MSGP) program (NAS 2019). That study recommended use of the latest aquatic life criteria for copper (i.e., the BLM) for setting stormwater benchmarks that are protective of aquatic life during short-term, intermittent exposure in stormwater.

    Based on the NAS (2019) recommendations, the EPA (2021) MSGP revised the copper benchmarks for stormwater using the EPA 2007 copper BLM. The EPA 2021 MSGP also allows operators to derive facility-specific stormwater benchmarks for copper using the copper BLM and representative ambient water chemistry data (e.g., the BLM parameter inputs).

    Given that the copper BLM provides both acute and chronic criteria and the NAS (2019) and EPA (2021) recommend the copper BLM for deriving stormwater benchmarks, it is a scientifically defensible approach for setting site-specific copper criteria. The number of ambient surface water samples in the Pajarito Plateau dataset from storm-flow monitoring reflects the site-specific hydrologic regime because most of the drainages do not flow or contain water except during or immediately following storm events.

    As part of the detailed analyses described in Appendix B to the Demonstration Report, DOE and N3B evaluated the importance of hydrologic regime on model development. The goal was to determine whether including different types of hydrologic categories (i.e., ephemeral, intermittent, and perennial) in the MLR significantly and meaningfully improved predictions of BLM criteria. Specifically, section B4.2 describes the outcome of this modeling exercise. While including these categories improved model fit (i.e., higher R^2), the improvement was insubstantial. For example, Table B5 shows the model parameters and R^2 (0.982) for a version of the MLR (referred to in section B4.2 as "Model 4") that includes unique intercepts for hydrologic categories. The proposed MLR (referred to in section B4.2 as "Model 5") excluded the hydrology categories, resulting in an $R^2 = 0.980$. This corresponds to a loss of 0.2% accuracy, which shows how little the hydrologic categories contribute to the MLR when DOC, hardness, and pH are also considered. Therefore, DOE and N3B present site-specific evidence that the MLR performs very well regardless of a stream's hydrologic regime.

NMED Comment

16. Appendix C Public Involvement Plan

To improve the Public Involvement Plan, the Department recommends N3B consider the following:

- *Provide additional outreach with Tribes and Stakeholders prior to public notice under this Public Involvement Plan given that Tribes and Stakeholders have added investment and potential impact from an action amending state water quality standards.*
- *Identify which local newspaper(s) will be used to distribute notification of the draft Demonstration.*
- *Notify the public of the Demonstration through a listserv (or equivalent) distribution mechanism given the general public will not be aware, unless through reading the newspaper, that there is a draft technical demonstration posing to amend state water quality standards.*

DOE Response

16. The public involvement plan has been revised as requested by NMED.

EPA COMMENTS

EPA Comment

1. The biotic ligand model (BLM) has been EPA's nationally recommended freshwater aquatic life criteria for copper under Clean Water Act Section 304(a) since 2007. The BLM version used as the basis for EPA’s 2007 copper criteria was version 2.2.3. The BLM reflects the latest scientific knowledge on copper bioavailability and toxicity with which to develop protective copper criteria. EPA recommends that states adopt the BLM as statewide copper criteria, but also supports site-specific application on a case-by-case basis.

DOE Response

1. Comment is addressed to NMED. DOE and N3B appreciate EPA’s statement that it “recommends that states adopt the BLM as statewide copper criteria, but also supports site-specific application on a case-by-case basis.”

EPA Comment

2. EPA’s water quality standards regulations at 40 CFR 131.11 provide that states should establish numeric criteria based on “(i) 304(a) Guidance; or (ii) 304(a) Guidance modified to reflect site- specific conditions; or (iii) Other scientifically defensible methods.” Because the BLM reflects the latest scientific knowledge on copper bioavailability and toxicity, EPA uses the copper BLM to evaluate the protectiveness of copper criteria, including site-specific criteria, that are developed based on 131.11(b)(1)(iii) “other scientifically defensible methods.”

DOE Response

2. Comment acknowledged.

EPA Comment

3. Data gathered to support development of alternative copper criteria at a site using a method like the copper BLM that accounts for site-specific characteristics should consider special circumstances that may affect copper toxicity throughout the expected range of receiving water conditions, considering both spatial and temporal variability. In this instance, since water chemistry data from a subset of the waterbodies to which the draft copper criteria are proposed to apply was used to develop the criteria, the supporting information for the criteria should clearly demonstrate that water chemistry data used to develop the criteria capture the full range of spatial variability in water chemistry of all waterbodies in the proposed action area. The supporting documentation should also demonstrate that data used to develop the proposed criteria are representative of the full range of temporal variability in receiving water chemistry conditions in these waterbodies, including both stormwater and, where applicable, baseflow conditions.

DOE Response

3. Section 5.1 of the report describes the full extent of water quality data measured in Pajarito Plateau waters. Water chemistry spanned the full range of the BLM's prescribed range (Table 5-2), with 14 of 531 samples being removed for extending beyond that range. Samples were excluded only to prevent potential BLM extrapolations when preparing the output dataset for MLR development. Figure 5-6 also provides a visualization of the ranges of MLR input and output data using 10th and 90th percentiles as reasonable bounds for MLR inputs. The MLR and BLM are very similar throughout the range of inputs even at the relative extremes of distributions.

   Table 6-1 describes the spatial extent for applying the MLR. Samples were collected from these waterbodies, including the reaches themselves and upstream and downstream reaches.

   Temporal variability is described by Figure 5-1, which illustrates when and where surface water samples were collected for BLM analysis between 2005 and 2019. Many of the watersheds were consistently sampled over that time except for low-sample periods, 2005–2006 and 2011–2012. Sampling was less frequent in Ancho, Chaquehui, Rito de Frijoles, and Jemez River watersheds, and all but Frijoles were sampled over multiple years. Therefore, temporal variability in water chemistry is well captured by the MLR.

EPA Comment

4. Accurate characterization of the input variables is also crucial to ensuring the resulting copper criteria protect aquatic life. Dissolved organic carbon (DOC) and pH have the greatest effect on the BLM results. When only total organic carbon (TOC) data are available, the proportion of organic carbon expected to be dissolved in surface waters should be estimated and used to scale the measured TOC value to DOC. The selected TOC to DOC conversion must be based on a scientifically sound rationale that should be explained in the public record for the criteria revision. A number of scientifically defensible options are available for the conversion, including using data from USGS' National Stream Quality Accounting Network (NASQAN) or Appendix C-2 of EPA's 2007 criteria document. The most conservative approach

would likely be to select the ratio resulting in the lowest DOC values, since lower DOC values result in lower (i.e. more stringent) BLM model outputs. EPA most recently addressed this issue of TOC to DOC conversions in its Draft Technical Support Document: Implementing the 2018 Recommended Aquatic Life Water Quality Criteria for Aluminum.

DOE Response

4. DOE and N3B agree with EPA's comment; the use of a TOC-to-DOC conversion factor is scientifically based and defensible. DOE and N3B's approach was both empirical and statistical in that the TOC and DOC were compared where both data were measured in site-specific samples, and then a conversion factor was derived mathematically. The value that was calculated in this way (0.86 or 86%) was then compared with several of EPA's recommended values and found to be quite similar. For example, the New Mexico stream-specific conversion factor is 81.5%, and the nationwide mean is 85.7% (EPA 2007), within rounding error of the selected value. While the lower New Mexico value reported in Appendix C-2 of EPA 2007 would also be defensible and is lower than the calculated value, the dataset suggests that the higher conversion factor is warranted (and supported by EPA's nationwide dataset). As such, DOE believes that the selected value is both scientifically defensible and reasonably conservative.

EPA Comment

5. ***In 2017 EPA entered into a Cooperative Research and Development Agreement (CRADA) with eight metals associations to collaborate in developing a simplified modeling approach that can predict the bioavailability and toxicity of metals, including copper, in the aquatic environment using the most current science. In its Phase 1 report, EPA found that the empirically-based multiple linear regression (MLR) models performed at least as well as the mechanistically-based BLM and stated that EPA intends to use MLR models as the overarching metals bioavailability- modeling approach with pH, hardness, and DOC as the core set of toxicity modifying factors to consider in model development. EPA is beginning work on development of MLR-based nationally recommended criteria for metals, including copper. Criteria development is expected to take several years. At this time, the copper BLM continues to reflect the best available science for protecting aquatic life from the toxic effects of copper, and EPA will continue to use the copper BLM to evaluate the protectiveness of submitted copper criteria.***

DOE Response

5. Comment acknowledged; thank you. The core set of toxicity modifying parameters determined to be most important in accurately generating BLM criteria in the current MLR analysis (pH, hardness, and DOC) is consistent with EPA's findings from Phase 1 of the Cooperative Research and Development Agreement (CRADA) and other scientific literature on copper toxicity (Brix et al. 2017).

REFERENCES

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ENCLOSURE 2

Copper Site-Specific Water Quality Criteria for the Pajarito Plateau: Demonstration Report

COPPER SITE-SPECIFIC WATER QUALITY CRITERIA FOR THE PAJARITO PLATEAU: DEMONSTRATION REPORT

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Acronyms

%HA	percent humic acid
AIC	Akaike's Information Criterion
APS	automated pump samplers
AU	Assessment Unit
BIC	Bayesian Information Criterion
BLM	biotic ligand model
BTV	background threshold value
CCC	Criterion Continuous Concentration
CFR	Code of Federal Regulations
CMC	Criterion Maximum Concentration
COC	chain of custody
CWA	Clean Water Act
DOC	dissolved organic carbon
DOE	US Department of Energy
DQA	data quality assessment
DQO	data quality objective
EIM	Environmental Information Management
EPA	US Environmental Protection Agency
ESA	Endangered Species Act
ID	identification
IP	Individual Permit
IPAC	Information for Planning and Consultation
IR	integrated report
LAC	Los Alamos County
LANL	Los Alamos National Laboratory
LOP	level of protection
MLR	multiple linear regression
MSGP	Multi-Sector General Permit
N3B	Newport News Nuclear BWXT Los Alamos
NMAC	New Mexico Administrative Code

NMED	New Mexico Environment Department
NPDES	National Pollutant Discharge Elimination System
ONRW	Outstanding National Resource Water
QA/QC	quality assurance/quality control
SSWQC	site-specific water quality criteria
SWQB	Surface Water Quality Bureau
TAL	target action level
TMDL	total maximum daily load
TOC	total organic carbon
USGS	United States Geological Survey
WER	water-effect ratio
Windward	Windward Environmental LLC
WQC	water quality criteria
WQCC	Water Quality Control Commission
WQS	water quality standards
WWTF	wastewater treatment facility

Executive Summary

This report describes the development of site-specific water quality criteria (SSWQC) for copper in surface waters of the Pajarito Plateau, in accordance with the US Environmental Protection Agency's (EPA's) nationally recommended ambient water quality criteria and New Mexico Water Quality Standards (20.6.4 NMAC) procedures for site-specific criteria.

In 2007, EPA issued revised nationally recommended freshwater aquatic life criteria for copper based upon the biotic ligand model (BLM) (EPA 2007a). EPA recognizes the BLM as best available science for setting copper criteria, because it explicitly considers the effects of multiple water chemistry parameters beyond hardness that affect the bioavailability of copper and its toxicity to aquatic life.

The BLM is recognized by the New Mexico Environment Department (NMED) as a more accurate method of assessing copper bioavailability than New Mexico's current hardness-based criteria (NMWQCC 2021). While New Mexico has not yet adopted EPA's ambient water quality criteria statewide because of the data needed to calculate BLM-based copper criteria, it has approved the BLM as a copper SSWQC method (20.6.4.10D(4)(c) NMAC).

Streams on the Pajarito Plateau have been extensively monitored under a variety of EPA and NMED programs over a 15-year period in order to make the Pajarito Plateau a suitable setting for developing BLM-based SSWQC. A site-specific dataset of BLM parameters was developed based on monitoring conducted from 2005 to 2019. The dataset includes a total of 531 discrete samples with sufficient water chemistry parameters to generate BLM-based criteria in accordance with EPA (2007a). Samples were collected from 50 different locations across 9 different watersheds and under a diverse set of hydrologic regimes.

Statistical evaluation of the site-specific dataset demonstrated that pH, dissolved organic carbon (DOC), and hardness account for 98% of the variation in BLM-based criteria for the Pajarito Plateau streams. The influences of other site-specific factors were considered, including hydrologic conditions (i.e., ephemeral, intermittent, or perennial regime), land use (i.e., developed or undeveloped areas), a major forest fire in 2011, and using different methods for predicting (or not predicting) DOC from total organic carbon (TOC). The statistical evaluation showed that the copper BLM can be simplified into the following acute Criterion Maximum Concentration (CMC) and chronic Criterion Continuous Concentration (CCC) equations while retaining a high degree of accuracy to and the scientific rigor of the BLM:

$$\boldsymbol{CMC = exp(-22.914 + 1.017 \times ln(DOC) + 0.045 \times ln(hardness) + 5.176 \times pH - 0.261 \times pH^2)} \quad \textbf{Equation ES-1}$$

$$CCC = exp(-23.391 + 1.017 \times ln(DOC) + 0.045 \times ln(hardness) + 5.176 \times pH - 0.261 \times pH^2) \quad \textbf{Equation ES-2}$$

This report demonstrates that these equations accurately estimate BLM-based criteria over the range of water chemistries and hydrologic regimes observed on the Pajarito Plateau. Therefore, these equations can be adopted as copper SSWQC for surface waters of the Pajarito Plateau to provide criteria that are protective of aquatic life uses in accordance with EPA recommendations (i.e., accurate to the BLM).

1 Introduction

On behalf of Newport News Nuclear BWXT Los Alamos (N3B), Windward Environmental LLC (Windward) has prepared this demonstration report, which describes the development of copper site-specific water quality criteria (SSWQC) for surface waters of the Pajarito Plateau in Los Alamos County (LAC), New Mexico. This report presents and justifies the derivation of a dissolved copper SSWQC in accordance with New Mexico Water Quality Standards (WQS) (20.6.4.10 New Mexico Administrative Code [NMAC]). It also presents the methods, available data, and spatial boundaries for deriving copper SSWQC for surface waters of the Pajarito Plateau.

New Mexico's current aquatic life water quality criteria (WQC) for copper (20.6.4.900 NMAC) are based on the 1996 US Environmental Protection Agency (EPA)-recommended copper criteria (EPA 1996), which were based on an equation that considered only the effect of water hardness on copper bioavailability and toxicity. EPA periodically revises its nationally recommended WQC for aquatic life to reflect current scientific knowledge. In 2007, EPA released updated Clean Water Act (CWA) §304(a) guidance for copper WQC to reflect new knowledge and an improved understanding of the effects of multiple water chemistry parameters on copper toxicity. The EPA (2007a)-recommended copper criteria reflect the "best available science" and significant advancements in scientific understanding of metal speciation, bioavailability, and toxicity.

Per EPA's recommendation, the biotic ligand model (BLM) incorporates these advancements and can be used to generate aquatic life WQC based on local water chemistry. The BLM builds on the old hardness-based criteria by incorporating additional water chemistry parameters that affect copper speciation, bioavailability, and toxicity. The current version of the copper BLM software is available through EPA (https://www.epa.gov/wqc/aquatic-life-criteria-copper).

The statistical model-based approach described in this report for developing copper SSWQC for surface waters of the Pajarito Plateau stems from EPA (2007a) recommendations for using the copper BLM and New Mexico WQS procedures to develop copper SSWQC. The physical and chemical characteristics (i.e., BLM parameters) of Pajarito Plateau surface waters have been rigorously monitored at a variety of locations, so it is a suitable setting to develop BLM-based copper SSWQC. The proposed SSWQC—multiple linear regression (MLR) equations that accurately predict BLM outputs using a subset of the BLM inputs—are intended for eventual use in all National Pollutant Discharge Elimination System (NPDES) permits and by New Mexico Environment Department (NMED) for CWA §303(d)/305(b) Integrated Assessments.

1.1 RATIONALE AND METHODS

Copper is an abundant trace element that occurs naturally in the earth's crust and an essential micronutrient required by virtually all plants and animals. At elevated concentrations, copper can have adverse effects on some forms of aquatic life, but such effects depend on site-specific chemistry. Both natural and anthropogenic sources introduce copper to Pajarito Plateau surface waters (Los Alamos National Laboratory [LANL] 2013; Windward 2020).

To protect aquatic life uses from copper toxicity, New Mexico's WQS establish the following state-wide dissolved copper criteria based on EPA's outdated 1996 ambient water quality criteria document (EPA 1996):

Acute criterion (µg/L) = exp(0.9422 × ln(hardness) – 1.700) × 0.96

Chronic criterion (µg/L) = exp(0.8545 × ln(hardness) – 1.702) × 0.96

As described by EPA (2018c), these hardness-based copper criteria were developed from an empirical relationship between toxicity and water hardness. Their development did not explicitly consider the effects of other water chemistry parameters that markedly affect copper bioavailability and toxicity.

In February 2007, EPA published *Aquatic Life Ambient Freshwater Quality Criteria – Copper* to address water chemistry parameters beyond hardness, and to reflect the latest scientific knowledge on copper bioavailability and toxicity (EPA 2007a). The criteria 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 scientific information, supplementing EPA's previously published recommendation 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 concentration of copper that will be protective of aquatic life." By taking a BLM-based approach, this demonstration report relies on the most recent available scientific information and EPA's current recommendations to develop copper SSWQC.

EPA's regulation at 40 Code of Federal Regulations (CFR) 131.11(b)(1)(ii) provides that states and tribes may adopt WQC that have been modified to reflect site-specific conditions. New Mexico WQS describe conditions under which SSWQC may be developed, including "physical or chemical characteristics at a site such as pH or hardness alter the biological availability and/or toxicity of the chemical" (20.6.4.10.D(1) NMAC). Consistent with EPA regulations, New Mexico WQS require a scientifically defensible method to derive SSWQC. The WQCC explicitly recognizes "the biotic ligand model as described in aquatic life ambient freshwater quality criteria – copper" (EPA 2007a) as one such scientifically defensible method to derive SSWQC (20.6.4.10.D(4) NMAC).

In addition, 40 CFR 131.20(a) requires that States adopt EPA Section 304(a) criteria or provide an explanation if not adopted when the results of the Triennial Review are submitted consistent with CWA section 303(c). As part of New Mexico's 2020 Triennial Review, EPA recommended that New Mexico update its aquatic life criteria for copper to reflect the latest science contained in the 304(a) copper criteria (EPA 2020). NMED stated in direct testimony that the BLM provides a more accurate assessment of copper bioavailability than New Mexico's hardness-based criteria calculation, but noted that it requires multiple water quality parameters (some of which are not commonly available) as a potential limitation of the copper BLM, and therefore, recommended that the WQCC not adopt the criteria state-wide. The limitation described in the 2020 Triennial Review is not an issue for the current proposal because BLM parameters have been sampled in Pajarito Plateau surface waters since 2005. Furthermore, the proposed copper SSWQC equations use only a subset of the BLM input parameters.

The EPA (2007a) copper BLM explicitly and quantitatively accounts for how individual water quality parameters affect the bioavailability and toxicity of copper to aquatic organisms. The BLM software relies on 12 water chemistry parameters as inputs to generate BLM-based WQC, but most parameters have little or no effect on the speciation, bioavailability, and toxicity of copper and, thus, on the magnitude of any resulting BLM-based WQC.[1]

To provide a more streamlined and transparent approach for adopting and implementing copper SSWQC for the Pajarito Plateau, BLM-based WQC were simplified into three-parameter acute and chronic equations using an MLR method. This approach is consistent with EPA's approach for setting WQC for other chemicals,[2] as well as with approaches described in the scientific literature for developing copper WQC (e.g., Brix et al. 2017) and EPA-approved approaches for simplifying the copper BLM into an MLR equation for SSWQC (EPA 2016a).

The proposed copper SSWQC equations were developed based on statistical analyses of BLM parameters monitored in Pajarito Plateau streams from 2005 to 2019. Three parameters (pH, dissolved organic carbon [DOC], and hardness) were found to have a significant impact on BLM-based criteria for the site-specific dataset. The SSWQC equations build upon New Mexico's current hardness-based equations to incorporate the combined effects of pH, hardness, and DOC. The evaluations presented in this

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[1] The BLM can also be used to evaluate the site-specific speciation, bioavailability, and toxicity of copper and several other metals. The sensitivity of the BLM's output to a given water chemistry parameter varies among different metals. When the BLM is being used to develop WQC for a single metal—in this case, copper—the model can be simplified to include only the sensitive parameters for that metal as model variables.

[2] For example, EPA-recommended aquatic life criteria for aluminum and ammonia are based on MLR equations that use multiple water quality parameters to generate criteria (EPA 2013, 2018b).

report demonstrate how the proposed SSWQC equations accurately estimate EPA (2007a) BLM-based copper criteria over the range of water chemistries and hydrologic regimes of the Pajarito Plateau.

1.2 REPORT CONTENTS

The remaining report is organized into the following sections:

- Regulatory background for establishing SSWQC (Section 2)
- Background on the physical setting, New Mexico WQS, permitted discharges, and monitoring programs (Section 3)
- Overview of scientific methods and regulatory processes for deriving SSWQC (Section 4)
- Summary of available surface water data and methods for deriving copper SSWQC (Section 5)
- Recommended copper SSWQC for surface waters of the Pajarito Plateau (Section 6)
- References cited (Section 7)

Additionally, there are four appendices to this report:

- Appendix A is a table of the data used to develop SSWQC.
- Appendix B provides additional details on the SSWQC development methods and results.
- Appendix C is the Public Involvement Plan (also see Section 2.1.5).
- Appendix D is an evaluation of threatened and endangered species (also see Section 2.5).

2 Regulatory Background

This section provides the regulatory background and framework for developing SSWQC in accordance with EPA guidance and New Mexico's WQS.

2.1 Regulatory Framework for Developing SSWQC

EPA's regulation at 40 CFR 131.11(b)(1)(ii) provides that states and tribes may adopt WQC that are "modified to reflect site-specific conditions." As with all criteria, SSWQC must be based on sound scientific rationale, protect designated uses, and are subject to EPA review and approval or disapproval under §303(c) of the CWA (EPA 2007a).

New Mexico's WQS (20.6.4.10.D NMAC) specify the following requirements for adopting SSWQC for New Mexico surface waters:

- Relevant site-specific conditions for developing SSWQC
- Protectiveness of SSWQC to designated uses
- Scientific methods for deriving SSWQC
- Petition and stakeholder/public review process for adopting SSWQC

Each factor is discussed in the following sections.

2.1.1 Relevant conditions for developing SSWQC

In accordance with New Mexico's WQS (20.6.4.10.D.1 NMAC), SSWQC may be adopted based on relevant site-specific conditions, such as:

- Actual species at a site are more or less sensitive than those used in the national criteria dataset.
- Physical or chemical characteristics at a site, such as pH or hardness, alter the biological availability and/or toxicity of a chemical.
- Physical, biological, or chemical factors alter the bioaccumulation potential of a chemical.
- The concentration resulting from natural background exceeds numeric criteria for aquatic life, wildlife habitat, or other uses if consistent with Subsection E of 20.6.4.10 NMAC.
- Other factors or combination of factors, upon review by Water Quality Control Commission (WQCC), may warrant modification of the default criteria, subject to EPA review and approval.

The rationale for the copper SSWQC described in this report is that water chemistry parameters beyond hardness alter the bioavailability and toxicity of copper to aquatic organisms (EPA 2007a). EPA recommends using the copper BLM to establish copper criteria, as the BLM incorporates the effects of multiple water chemistry parameters and reflects the best available scientific information.

NMED recognizes that the BLM represents the best available science for setting copper WQC (NMWQCC 2021). It recommended that within New Mexico the BLM be adopted on a site-specific basis. Because LANL has analyzed BLM parameters for a large number of surface water samples from the Pajarito Plateau (Appendices A and B), site-specific adoption of the BLM for waters of the Pajarito Plateau is appropriate and consistent with the New Mexico WQS. The BLM-based proposed SSWQC are based on statistical evaluations that demonstrate that pH, DOC, and hardness have a significant effect on accurately generating BLM-based copper criteria, consistent with findings that others have reported (EPA 2007a). Additional discussion of Pajarito Plateau-specific water chemistry conditions and how they influence copper criteria is provided in Section 5 (e.g., Sections 5.1, 5.3, and 5.4).

2.1.2 Protectiveness of SSWQC

In accordance with 20.6.4.10.D.2 NMAC, "site-specific criteria must fully protect the designated use to which they apply." The copper SSWQC described in this report are based on EPA (2007a) criteria for protection of aquatic life uses and will fully protect aquatic life uses on the Pajarito Plateau to the same extent as the EPA (2007a) criteria.

Relative to hardness-based copper WQC for aquatic life, EPA (2007a) reports:

> 'Stringency' likely varies depending on the specific water chemistry of the site. The 1986 hardness-based equation and resulting copper criteria reflected the effects of water chemistry factors such as hardness (and any of the other factors that were correlated with hardness, chiefly pH and alkalinity). However, the hardness based criteria, unadjusted with the WER [water effect ratio], did not explicitly consider the effects of DOC and pH, two of the more important parameters affecting copper toxicity. The application resulted in copper criteria that were potentially under-protective (i.e., not stringent enough) at low pH and potentially over-protective (i.e., too stringent) at higher DOC levels.
>
> By contrast, the BLM-based recommended criterion should more accurately yield the level of protection intended to protect and maintain aquatic life uses. By using the latest science currently available, application of the BLM-derived copper criteria should be neither under-protective nor over-protective for protection and maintenance of aquatic life uses affected by copper.

BLM-based WQC may be higher or lower than hardness-based WQC, depending on water chemistry. When the BLM-based WQC are lower, they are sometimes mistakenly referred to as "more stringent" (and vice-versa). Rather, changes in the

BLM-based WQC reflect changes in water chemistry and copper bioavailability, not changes in the stringency (i.e., level of protection [LOP]). As described by EPA (2021), BLM-based criteria will in some cases be higher and in other cases be lower than hardness-based criteria. "Although there is not a single water quality criteria value to use for comparison purposes, the BLM-based water quality criteria for copper provides an improved framework for evaluating a 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" (EPA 2021).

Thus, BLM-based copper SSWQC described in this report will fully protect aquatic life uses on the Pajarito Plateau in accordance with EPA recommendations.

As part of this evaluation, Rio Grande water chemistry data from the National Water Quality Monitoring Council's Water Quality Portal website (National Water Quality Monitoring Council 2019) were considered to ensure that the SSWQC would not affect waters downstream of the Pajarito Plateau. The Rio Grande has not been listed as impaired due to copper in past 303(d) evaluations presented in New Mexico's integrated reports (IRs) (e.g., NMED 2018), neither above nor below confluences with Pajarito Plateau tributaries. Using New Mexico's current hardness-based copper criteria, the copper BLM, and the simplified SSWQC, copper concentrations in the Rio Grande were found not to exceed any criteria (more detail in Section 5.6). Therefore, a change on the Pajarito Plateau from the hardness-based criterion to the SSWQC would not adversely impact the Rio Grande downstream of its confluence with plateau tributaries.

No changes are proposed to existing or designated aquatic life uses or for non-aquatic life criteria such as irrigation, livestock watering, wildlife habitat, primary or secondary human contact, or drinking water. In addition, the proposed SSWQC change is not associated with new discharges of copper nor changes to existing discharges of copper.

2.1.3 Scientific methods for SSWQC

Under 20.6.4.10.D.4 NMAC, "a derivation of site-specific criteria shall rely on a scientifically defensible method, such as one of the following:

(a) the recalculation procedure, the water-effect ratio procedure metals procedure or the resident species procedure as described in the water quality standards handbook (EPA-823-B-94-005a, 2nd edition, August 1994)

(b) the streamlined WER procedure for discharges of copper (EPA-822-R-01-005, March 2001)

(c) the biotic ligand model as described in aquatic life ambient freshwater quality criteria – copper (EPA-822R-07-001, February 2007)

(d) the methodology for deriving ambient water quality criteria for the protection of human health (EPA-822-B-00-004, October 2000) and associated technical support documents; or

(e) a determination of the natural background of the water body as described in Subsection E of 20.6.4.10 NMAC."

In accordance with current EPA recommendations, the copper SSWQC described in this report were developed using the copper BLM and site-specific water chemistry to reflect copper bioavailability under varying water chemistry conditions on the Pajarito Plateau.

Prior to its publication of the 2007 copper criteria document, EPA recommended the water-effect ratio (WER) procedure to adjust copper criteria "to address more completely the modifying effects of water quality than the hardness regressions achieve" (EPA 2007a). EPA's Science Advisory Board found that compared to the WER procedure, the BLM can significantly improve predictions of copper toxicity to aquatic life across an expanded range of water chemistry parameters (EPA 2000).

As described in Section 5 of this report, EPA's BLM method was streamlined to substitute simple MLR equations for acute and chronic SSWQC[3] from a relatively complex software-based model. MLR is also a scientifically defensible method for generating WQC as a function of multiple water chemistry parameters (Section 4.3). Given the high degree of agreement between the MLR-predicted and BLM-based WQC (Section 5.4.2) and the scientific rigor associated with the BLM, the copper SSWQC presented in this report meet the 20.6.4.10.D.4 NMAC requirement that SSWQC be derived based on a scientifically defensible method.

[3] The proposed SSWQC equations are analogous to the hardness-based equations used in the statewide WQS for copper, but the proposed SSWQC equations are more accurate because they include DOC and pH in addition to hardness.

2.1.4 Copper SSWQC petition

In accordance with WQCC regulations (20.1.6.200.A and 20.6.4.10.D(3) NMAC), any person may petition the WQCC to adopt SSWQC. WQCC regulations require that a petition for the adoption of SSWQC "be in writing and shall include a statement of the reasons for the regulatory change. The petition shall cite the relevant statutes that authorize the commission to adopt the proposed rules and shall estimate the time that will be needed to conduct the hearing. A copy of the entire rule, including the proposed regulatory change, indicating any language proposed to be added or deleted, shall be attached to the petition. The entire rule and its proposed changes shall be submitted to the commission in redline fashion, and shall include line numbers" (20.1.6.200.B NMAC). In addition, the regulations at 20.6.4.10.D(3) NMAC require that a petition do the following:

(a) Identify the specific waters to which the SSWQC would apply.

(b) Explain the rationale for proposing the SSWQC.

(c) Describe the methods used to notify and solicit input from potential stakeholders and from the general public in the affected area, and present and respond to the public input received.

(d) Present and justify the derivation of the proposed SSWQC.

LANL will develop a draft petition for copper SSWQC based on: 1) conclusions and recommendations presented herein, 2) NMED and EPA comments on this report, and 3) input from other potential stakeholders, tribes, and the general public. The petition will include all information required under 20.1.6.200 and 20.6.4.10 NMAC for WQCC review.

2.1.5 Public involvement plan

A public involvement plan was developed to outline the general process and schedule for public, tribal, and stakeholder involvement in the development of the copper SSWQC. The complete plan is provided in Appendix C. Specific objectives of the plan are as follows:

- Identify potential stakeholders, tribes, and general public members who may be affected by the proposed copper SSWQC.
- Establish a process to present the proposed copper SSWQC to stakeholders, tribes, and the general public.
- Establish a process to receive and respond to input from stakeholders, tribes, and the general public on the proposed copper SSWQC.
- Develop a draft schedule for stakeholder, tribal, and general public engagement.

2.2 ANTIDEGRADATION

New Mexico's antidegradation policy (20.6.4.8 NMAC) applies to all surface waters of the state and to all activities with the potential to adversely affect water quality or existing or designated uses. Such activities include::

- Any proposed new or increased point source or nonpoint source discharge of pollutants that would lower water quality or affect the existing or designated uses
- Any proposed increase in pollutant loadings to a waterbody when the proposal is associated with existing activities
- Any increase in flow alteration over an existing alteration
- Any hydrologic modifications, such as dam construction and water withdrawals (NMED 2020a)

This petition does not propose new activities that could impact water quality or existing or designated uses on the Pajarito Plateau. Instead, it proposes updated copper WQC intended to more accurately achieve the level of protection for aquatic life stipulated by EPA guidance (Section 2.1.2). Therefore, an antidegradation review is not required for the proposed SSWQC.

If the proposed copper SSWQC are adopted by the WQCC into New Mexico's WQS, the SSWQC would establish the "level of water quality necessary to protect existing or designated uses" for any future antidegradation review related to any new proposed activity, as defined under New Mexico's antidegradation policy and in accordance with EPA recommendations for the protection of aquatic life uses (Section 2.1.2).

2.3 NEW MEXICO WQS FOR PAJARITO PLATEAU SURFACE WATERS

Most water bodies on the Pajarito Plateau are classified in New Mexico WQS as ephemeral or intermittent waters (20.6.4.128 NMAC), which are designated as providing limited aquatic life use. According to NMAC, these water bodies are subject to acute criteria only. Only a few water bodies in the area are classified as perennial (20.6.4.121 and 20.6.4.126 NMAC), which are subject to both acute and chronic aquatic life criteria (i.e., Upper Sandia Canyon associated with wastewater treatment plant discharges; isolated segments of Cañon de Valle and Pajarito Canyon associated with local springs; and El Rito de los Frijoles in Bandelier National Monument). Unclassified surface waters (20.6.4.98 NMAC) are designated as providing a marginal warmwater aquatic life use, to which both acute and chronic aquatic life criteria apply. As discussed in Section 5, the proposed copper SSWQC include both acute and chronic criteria equations, so they can be applied as appropriate in accordance with NMAC surface water classifications.

NMED has assigned Assessment Units (AUs) to various surface water segments across the Pajarito Plateau; there are 50 AUs, many of which are located within the Laboratory or receive discharges regulated by the Individual Permit (IP), the Multi-Sector General Permits (MSGP), the LANL industrial discharges, or the LAC wastewater treatment facility (WWTF) permit. New Mexico's most recent CWA §303(d)/305(b) IR for the 2020 to 2022 assessment cycle identifies multiple AUs impaired for aquatic life uses due to exceedances of NMED's hardness-based copper WQC, along with other causes (NMED 2020b). The IR impairment category provided for copper in these surface waters is 5/5B, defined as "impaired for one or more designated or existing uses and a review of the water quality standard will be conducted" (NMED 2018). The assessment rationale for the 2020 to 2022 IR explains that "[s]pecific impairments are noted as IR Cat 5B to acknowledge LANL's ongoing discussions and research regarding applicable water quality standards on the Pajarito Plateau for these parameters." The copper SSWQC described herein, being based on the best available science and current EPA recommendations, should provide more appropriate copper criteria for NMED's CWA §303(d)/305(b) assessments and other site assessments conducted by LANL.

2.4 NPDES DISCHARGES

The NPDES permit regulates four principal types of discharges to Pajarito Plateau waters:

- Stormwater discharges associated with legacy contamination and industrial activities are regulated under the LANL's NPDES Storm Water IP (No. NM0030759).
- Stormwater discharges associated with current industrial activities are regulated under EPA NPDES MSGPs (Nos. NMR050011, NMR050012, and NMR050013).
- Industrial and sanitary wastewater and cooling water discharged from 11 outfalls are regulated under NPDES Permit No. NM0028355.
- Municipal sanitary wastewater discharged to Lower Pueblo Canyon by the LAC WWTF is regulated under NPDES Permit No. NM0020141.

These NPDES permits generally require water quality monitoring and certain actions based on concentrations of copper and other parameters. Current IP target action levels (TALs), MSGP benchmarks, and water quality-based effluent limits for copper applicable to Laboratory NPDES wastewater permits are based on New Mexico's hardness-based dissolved copper criteria (20.6.4.900 NMAC). In its 2019 draft IP Fact Sheet (EPA 2019), EPA suggested that BLM-based values may be considered for effluent benchmarks if BLM-based copper SSWQC are adopted into New Mexico WQS, and if NMED and N3B reach mutually agreeable BLM values through the annual sampling implementation plan. The copper SSWQC presented in this report are intended for eventual use in all NPDES permits and by NMED for CWA §303(d)/305(b) Integrated Assessments.

2.5 THREATENED AND ENDANGERED SPECIES

Possible effects of copper SSWQC on threatened and endangered species under the federal Endangered Species Act (ESA) were considered as part of this analysis. The Information for Planning and Consultation (IPAC) tool from the US Fish and Wildlife Service's Environmental Conservation Online System website (USFWS 2018) was used to identify listed species potentially present on the Pajarito Plateau and in downstream waters of the Rio Grande. The proposed scope for the SSWQC includes all watersheds from Guaje Canyon in the north to El Rito de Frijoles in the south, as well as from the headwaters of each canyon to the west and their confluences with the Rio Grande to the east. The following species were determined by the IPAC tool to be potentially present on the Pajarito Plateau or in Rio Grande waters (within a reasonable distance downstream of its confluence with Pajarito Plateau streams)[4]:

- New Mexico jumping mouse (*Zapus hudsonius luteus*)
- Mexican spotted owl (*Strix occidentalis lucida*)
- Southwestern willow flycatcher (*Empidonax traillii extimus*)
- Yellow-billed cuckoo (*Coccyzus americanus*)
- Jemez Mountains salamander (*Plethodon neomexicanus*)
- Rio Grande cutthroat trout (*Oncorhynchus clarkii virginalis*)
- Rio Grande silvery minnow (*Hybognathus amarus*)

Critical habitat for Mexican spotted owl and Jemez Mountains salamander would fall within the area potentially affected by the SSWQC (Map 3-1), and Rio Grande silvery minnow critical habitat is downstream of these waters. Each species is briefly evaluated and discussed in Appendix D. Based on these evaluations, it is not expected that implementation of the proposed SSWQC would adversely affect ESA-listed species (directly or indirectly) or their critical habitats.

In general, the species listed above are terrestrial and feed on terrestrial prey (Appendix D), suggesting that exposures to dissolved copper in Pajarito Plateau watersheds should be infrequent. Moreover, the copper BLM (and, by extension, the proposed SSWQC) represents criterion levels intended to be protective of sensitive aquatic species, including salmonids and cyprinids like the Rio Grande cutthroat trout and silvery minnow. It also protects potential prey items of these fish and other species.

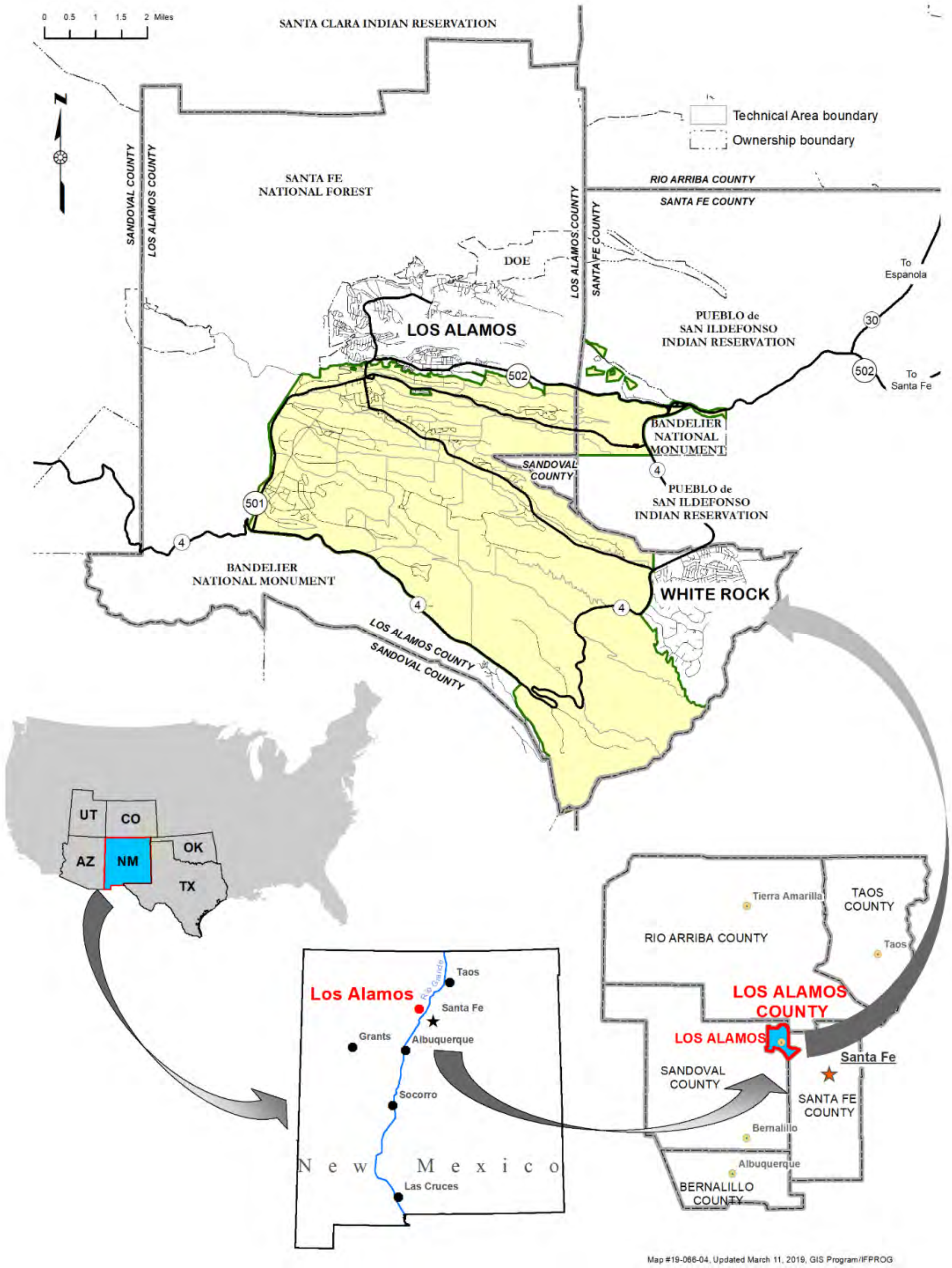
[4] A polygon was drawn using IPAC that included the Pajarito Plateau watersheds plus a 2 mile (approximate) buffer around the plateau (all watersheds). This captured the Rio Grande below the confluence with Pajarito Plateau watersheds.

3 Site Background

The following sections provide general background information on the physical setting, New Mexico's WQS, permitted discharges, and surface water monitoring programs for the Pajarito Plateau.

3.1 GEOGRAPHIC SETTING

The Laboratory occupies approximately 36 square miles of US Department of Energy (DOE) lands in LAC in north-central New Mexico, approximately 60 miles north-northeast of Albuquerque and 25 miles northwest of Santa Fe (Figure 3-1). The general region encompassing the Laboratory, towns of Los Alamos and White Rock, Bandelier National Monument, San Ildefonso Pueblo lands, western slopes of the Jemez Mountains, and other surrounding areas is known, geographically, as the Pajarito Plateau. Lands north, west, and south of the Laboratory are largely undeveloped areas held by the Santa Fe National Forest, US Bureau of Land Management, Bandelier National Monument, and LAC (LANL 2013). The communities closest to the Laboratory are the towns of Los Alamos, located just to the north of the main Laboratory complex, and White Rock, located a few miles to the east-southeast.



Source: Hansen et al. (2020)

Figure 3-1. Geographic setting for LANL BLM dataset

3.2 GEOLOGIC SETTING

The Laboratory is situated on fingerlike mesas capped mostly by Bandelier Tuff. The Bandelier Tuff consists of ash fall, pumice, and rhyolite tuff that vary from 1,000 feet thick on the western side of the plateau to about 260 ft thick eastward above the Rio Grande (Broxton and Eller 1995). The mesa tops slope from elevations of approximately 7,800 feet on the flanks of the Jemez Mountains to about 6,200 feet at the mesas' eastern terminus above the Rio Grande Canyon. Natural background copper concentrations in Bandelier Tuff range from 0.25 to 6.2 mg/kg with a median of 0.665 mg/kg (Ryti et al. 1998).

Background copper concentrations in Pajarito Plateau surface waters were recently characterized by Windward (2020). Based on surface water samples collected by LANL between 2015 and 2018, Windward estimated that background dissolved copper concentrations draining from undeveloped landscapes (i.e., excluding the influence of urban runoff) are fairly low (≤ 5.6 µg/L).

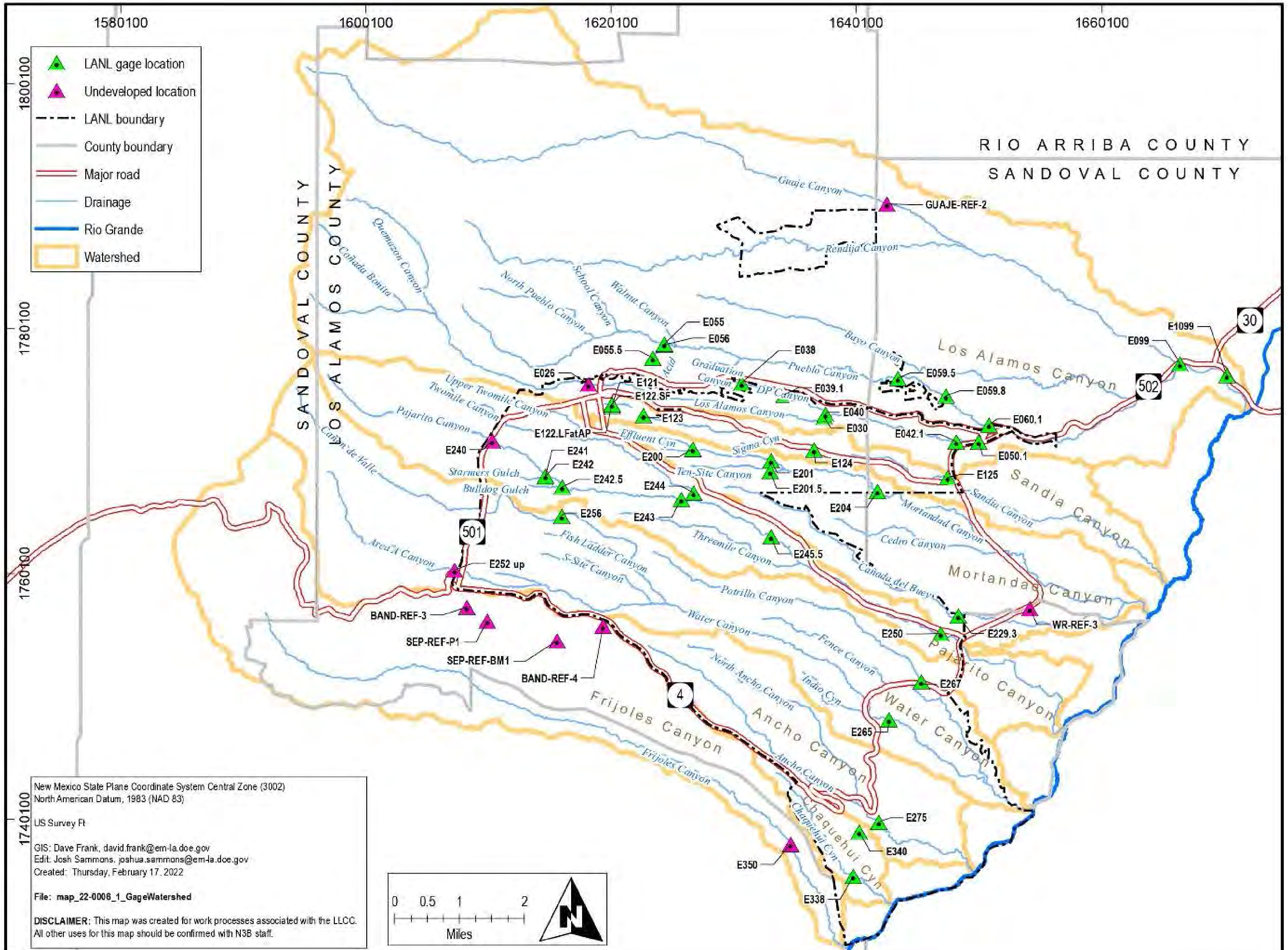
3.3 HYDROLOGIC SETTING

The Laboratory lies within a segment of the upper Rio Grande Basin denoted by the US Geological Survey eight-digit hydrologic unit code 13020101. The upper Rio Grande Basin is a large watershed (approximately 7,500 square miles) that generally flows from north to south. The New Mexico portion of the basin falls within seven counties: Rio Arriba, Taos, Santa Fe, Los Alamos, Sandoval, Mora, and San Miguel.

Surface water runs off the adjacent Jemez Mountains and Pajarito Plateau through steep and narrow canyons, flowing primarily southeast to the Rio Grande; however, surface water flows rarely reach the Rio Grande due to the limited flow durations and infiltration in canyon reaches upgradient of the Rio Grande (N3B 2020; Hansen et al. 2020). Most drainages on the Pajarito Plateau are currently classified as ephemeral or intermittent, because flow only occurs for limited periods in response to rainfall or snowmelt. Summer monsoonal thunderstorms are the sole contributors to flow in the many ephemeral waters, which otherwise remain dry for most of the year. A few canyons contain relatively short segments of intermittent and/or perennial flow attributable to springs, snowmelt, and industrial/municipal effluent discharges. Flows either represent stormflow (e.g., in response to precipitation events) or baseflow conditions, with baseflow generally being limited to perennial reaches and stormflow dominating other reaches.[5]

[5] For the purpose of this discussion, "baseflow" includes both natural baseflow and effluent. For example, "baseflow" in Upper Sandia Canyon is effluent dominated or effluent dependent.

The Laboratory encompasses seven major watersheds: Los Alamos, Sandia, Mortandad, Pajarito, Water/Cañon de Valle, Ancho, and Chaquehui Canyons. Many tributaries to these canyons are identified within the Laboratory as smaller sub-watersheds with other names. Additional sub-watersheds outside of the Laboratory include the 20.6.4.98 NMAC waters to the north (e.g., Pueblo, Bayo, Guaje, and Rendija Canyons and their tributaries). Frijoles Canyon, located to the south of the Laboratory, is another major watershed on the Pajarito Plateau. A depiction of the Pajarito Plateau, related water bodies, surface water sampling locations, the Laboratory, the towns of Los Alamos and White Rock, and Pueblo and County boundaries is presented in Map 3-1.



Map 3-1. **Sampling locations for BLM data on the Pajarito Plateau**

3.4 SAMPLING AND ANALYSIS PROGRAMS

This section provides a brief description of the sampling programs under which surface water quality data used to develop the copper SSWQC were collected. All samples included in the BLM dataset (Appendix A) were collected under sampling and analysis programs, validated, and reported previously to NMED under the various sampling programs described below.

3.4.1 Sampling

LANL conducts various surface water quality monitoring programs at many locations on the Pajarito Plateau. The programs are typically related to permit compliance monitoring and monitoring required under the NMED (2016) Compliance Order on Consent, although periodic investigative studies are also conducted to better understand and manage surface waters on the plateau. LANL is not obligated to sample and analyze for BLM parameters but has generally done so in response to EPA recommendations for developing aquatic life criteria for metals (EPA 2007a).[6]

Although surface water samples are sometimes collected as discrete grabs, most samples collected by LANL to date have been through its network of automated pump samplers (APS) located at various streamflow gaging stations. These devices are triggered when there is sufficient streamflow, often generated by a storm (typically during the summer monsoon season).[7] When there is sufficient flow, an internal pump initiates, drawing surface water into a series of sample bottles that remain in the APS until collected by a field technician (typically within 24 to 48 hours). Regardless of the sampling method, all samples are collected in pre-cleaned bottles to prevent contamination. The technician delivers the bottles to a sample processing facility, where each bottle is refrigerated, filtered, and/or chemically preserved as appropriate for the target analytes. Next, the sample is transferred to the sample management office and finally to LANL's contract laboratory for chemical analysis. This process is carried out by trained and qualified personnel under approved standard operating procedures (see Section 3.4.2). Quality control/quality assurance (QA/QC) measures are maintained during the sampling and transport processes, including the collection of field duplicates and maintenance of field blanks. Chain of custody (COC) forms are used to track the collection and delivery of samples to laboratories. Appendix A

[6] BLM parameters that have been consistently analyzed by LANL include pH, DOC, calcium, magnesium, alkalinity, potassium, sulfate, and chloride. Temperature, %HA, and sulfide values are generally not determined and have been assumed, as discussed in Section 4.2.

[7] APS are generally in operation during the summer, when storm events result in sufficient flow; outside of this time period, samples cannot be collected consistently, so APS are not always in operation. Therefore, multi-seasonal datasets cannot be established for many streams on the Pajarito Plateau. Multi-seasonal data are available, however, for perennial reaches such as Upper Sandia Canyon (Appendix A).

provides COC numbers associated with each sampling event, as well as the sample collection and retrieval dates/times and laboratory receipt and analysis dates/times.

Due to the ephemeral/intermittent nature of many of the drainages, most surface water samples are collected during the late spring to early fall, during the monsoon season. However, samples are also collected during other parts of the year in perennial stream segments. Figure 3-2 summarizes the distribution of sampling over the year by month and season for the samples included in the BLM dataset (Appendix A).[8]

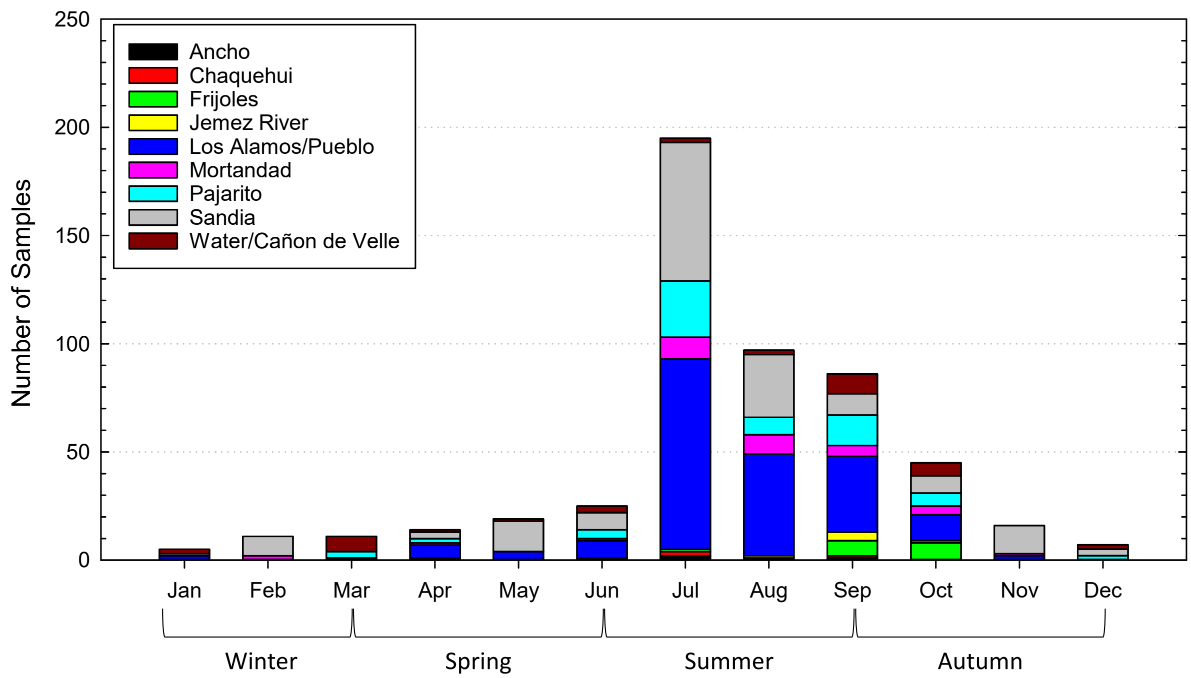


Figure 3-2. Distribution of BLM samples by watershed and season, 2005 to 2019

All BLM data from 2005 to 2019 were collected as part of five general programs in accordance with the laboratory and data validation procedures described in Section 3.4.2:

- Annual Site Environmental Report Program
- Los Alamos/Pueblo Canyon Sediment Monitoring Program
- Mortandad/Sandia Chromium Investigation and General Surveillance
- Sandia Wetlands Performance Monitoring Program
- Supplemental Environmental Program

[8] Figure 5-1 presents the sampling distribution similar to Figure 3-2 but across years instead of seasons.

Each of the sampling programs is associated with a sampling and analysis plan, which describes the sampling and analytical QA/QC for that program. Because they rely on similar samples and analytical data, these plans are comparable in scope and content.

3.4.2 Laboratory analysis and data validation

LANL contracted with several laboratories to analyze its surface water data between 2005 and 2019:

- General Engineering Laboratories, Inc., Charleston, South Carolina
- Environmental Sciences Division, Los Alamos, New Mexico
- Desert Research Institute, Reno, Nevada
- Cape Fear Analytical, Wilmington, North Carolina
- Brooks Applied Laboratories, Bothell, Washington

LANL's contract laboratories analyze the samples using standard analytical methods, usually EPA methods. The following methods are used:

- EPA 150.1 (pH)
- EPA 310.1 (alkalinity)
- SM-A2340B (hardness)
- SW-9060 (organic carbon)
- EPA 300.0 (anions – sulfate and chloride)
- EPA 200.7 and 200.8 and SW-846 methods 6010C, 6020, and 6020b (metals by inductively coupled plasma)

Each analytical method is considered appropriate and scientifically defensible for analysis of BLM parameters (EPA 2007b).

LANL's contract laboratories follow standard QA/QC procedures for analysis and data reporting and are accredited under the DOE Consolidated Audit Program for the analytes of interest. Detection and reporting limits are provided with samples, and non-detections are flagged by the laboratory and checked by independent data validators. Appendix A provides the detection status for each sample in the copper SSWQC database. When copper was not detected, reported results in Appendix A are equal to the detection limit.

N3B data validation is performed externally from the analytical laboratory and end-users of the data. This data validation process applies a defined set of performance-based criteria to analytical data that may result in the qualification of that data. Data validation provides a level of assurance, based on this technical evaluation, of the data quality.

Laboratory analytical data are validated by N3B personnel as outlined in N3B-PLN-SDM-1000, Sample and Data Management Plan; N3B-AP-SDM-3000, General Guidelines for Data Validation; N3B-AP-SDM-3014, Examination and Verification of Analytical Data; and additional method-specific analytical data validation guidelines. All procedures have been developed, as applicable, from the EPA QA/G-8 *Guidance on Environmental Data Verification and Data Validation* (EPA 2002), *Department of Defense/Department of Energy Consolidated Quality Systems Manual (QSM) for Environmental Laboratories* (DoD and DOE 2019), and the EPA national functional guidelines for data validation (EPA 2017, 2020).

N3B validation of chemistry data includes a technical review of the analytical data package. This review covers the evaluation of both field and laboratory QC samples, the identification and quantitation of analytes, and the effect of QA/QC deficiencies on analytical data, as well as other factors affecting data quality.

The analytical laboratory uploads the data as an electronic data deliverable to the N3B Environmental Information Management (EIM) database. The data are then validated both manually and using EIM's automated validation process. Validated results are reviewed by an N3B chemist before being fully transferred to the EIM database.

This validation follows processes described in the N3B validation procedures listed above. Validation qualifiers and codes applied during this process are also reviewed and approved by an N3B chemist to assess data usability. The EIM data are then made available to the public in the Intellus New Mexico database (Intellus 2019). Any data rejected during data validation were not used to develop the copper SSWQC. Additionally, any data in Intellus with a BEST_VALUE_FLAG reported as "N" was excluded.[9]

[9] Some surface water samples were analyzed multiple times for the same analyte, with each analytical result being reported in Intellus; one of those measurements may have been flagged as the "best." Data reported with a BEST_VALUE_FLAG of "Y" in Intellus were used to develop the copper SSWQC, whereas those with a flag of "N" were excluded.

4 Methods for Developing SSWQC

The following sections describe the technical and regulatory basis for the BLM and the resulting MLR-based SSWQC, which were developed using BLM input and output data (Appendix A).

4.1 Background on the BLM

The copper BLM is a software tool that mechanistically describes, and can predict, the bioavailability of copper under a wide range of water chemistry conditions observed in ambient surface waters. The copper BLM is scientifically robust and defensible, EPA recommended, and freely available. BLMs have been developed for metals in both freshwater and saltwater environments; however, to date, EPA has only released nationally recommended BLM-based WQC for copper. A general schematic for the BLM is depicted in Figure 4-1; arrows show the mechanistic relationships among various water quality parameters, the dissolved metal ("Me^{n+}"), and the biotic ligand, represented by the gill surface of an aquatic organism (or a homologous respiratory organ).

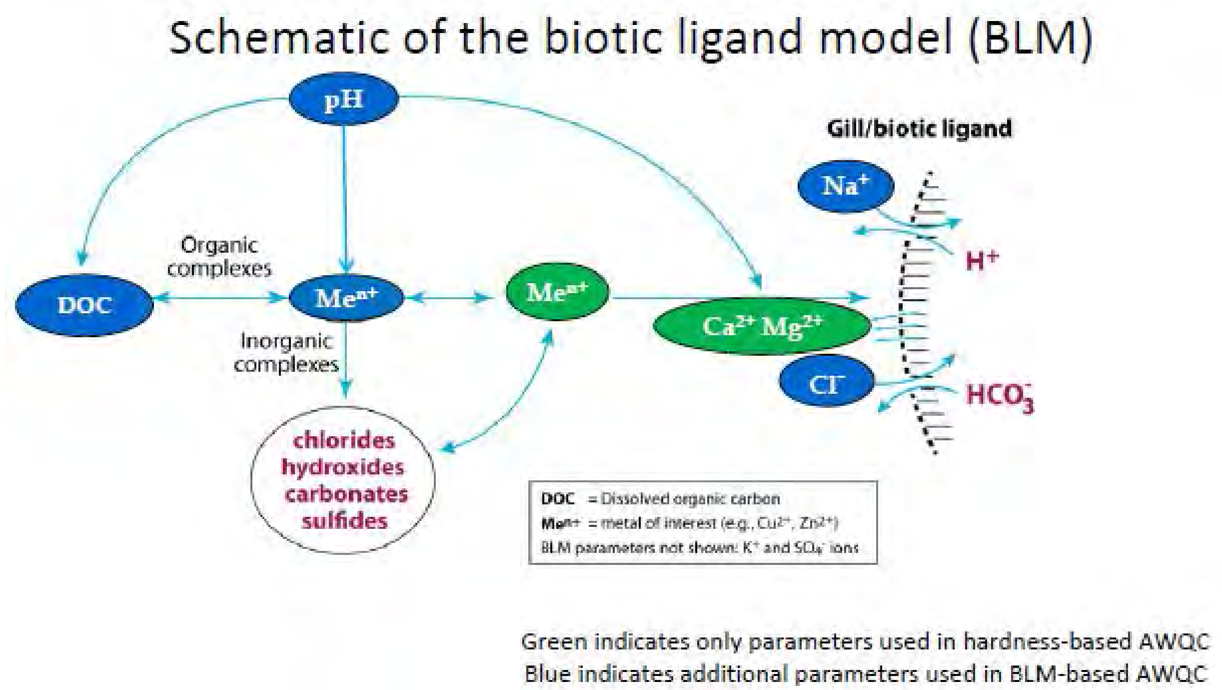


Figure 4-1. Schematic of the BLM

The BLM executable program that drives the Windows Interface version of the BLM software can be used to perform BLM calculations efficiently for large datasets. The Windows Interface version of the software (version 3.41.2.45) was used when developing this report.

The BLM's ability to incorporate metal speciation reactions and organism interactions allows for the prediction of metal effect levels associated with a variety of organisms over a wide range of water quality conditions. Accordingly, the BLM is a defensible and relevant method for deriving WQC across a broad range of water chemistry and physical conditions (EPA 2007a). It generates both acute (i.e., Criterion Maximum Concentration [CMC]) and chronic (i.e., Criterion Continuous Concentration [CCC]) criteria applicable to all aquatic life use categories specified in 20.6.4.10 NMAC.

The copper BLM is also applicable to stormwater flow and NPDES benchmarks. In 2019, EPA sponsored a study conducted by the National Academies of Sciences, Engineering, and Medicine's National Research Council for updating stormwater benchmarks under EPA's MSGP program (NAS 2019). Based on that study, EPA (2021) recommends that the copper BLM be used to derive stormwater benchmarks in accordance with EPA 304(a) guidance. EPA has also included stipulations for the use of the copper BLM at industrial facilities as part of the 2021 MSGP; the BLM may be used to show whether facility-specific discharge concentrations that exceed the generic MSGP copper benchmarks are in compliance.

4.2 Description of BLM Inputs and Functions

The copper BLM (EPA 2007a) utilizes 12 water quality parameters: pH, DOC, calcium, magnesium, sodium, potassium, sulfate, chloride, alkalinity, temperature, percent humic acid (%HA), and sulfide. While %HA is an input parameter, it is rarely measured in ambient surface waters, so the BLM user's guide recommends a default value of 10% (HydroQual 2007; Windward 2017). The selected default value for total sulfide was the recommended value from Windward (2019) of 1×10^{-10} mg/L, which is appropriate when sulfide data are not available. Total sulfide does not influence the copper BLM, however a small non-zero value is required to calculate BLM output. Measured copper concentrations are not needed to generate BLM-based WQC. For Pajarito Plateau samples, BLM inputs can all be found in Appendix A.

EPA (2007a, 2016b) provides guidance for developing datasets suitable for generating BLM-based copper WQC, including how a given parameter can be estimated from other parameters or regional datasets or set to a default value. A general overview of these approaches is described below. Section 5.1 and Appendix B describe the development of the site-specific BLM dataset for the Pajarito Plateau.

Generally, measured concentrations in water samples that have been filtered through a 0.45-µm filter (i.e., operationally defined as dissolved concentrations) are used as BLM inputs. If it can be demonstrated that dissolved and total (unfiltered) concentrations of BLM inputs are similar, then total concentrations can be substituted for dissolved concentrations if the latter are not available for a given sample.

In addition to substitution approaches, it may be necessary to estimate concentrations for some BLM input parameters based on other measured parameters. For example, calcium and magnesium may be estimated from hardness, DOC may be estimated

from total organic carbon (TOC), and other cations or anions may be estimated from their relationships with conductivity or specific conductance. This estimation approach is contingent upon a demonstration that such estimates are appropriate and defensible.

Another approach to substituting missing BLM inputs makes use of the ecoregion-specific "default" estimates proposed by EPA (2016b). Oregon uses this approach to generate "default" copper WQC for purposes of initial screening assessments (Oregon DEQ 2016a, b; McConaghie and Matzke 2016), although state-specific datasets are used rather than EPA (2016b) values. This approach was not needed when aggregating data for the Pajarito Plateau for the analysis described herein, because sufficient water quality data were available (Section 5.1).

4.3 Use of MLR in Developing WQC

An MLR approach was used to develop a site-specific, three-parameter equation that accurately predicts BLM-based copper WQC for surface waters of the Pajarito Plateau using pH, DOC, and hardness values (Sections 5.3, 5.4, and 6). This approach parallels the one adopted in Georgia in 2016, whereby a two-parameter, BLM-based MLR equation was approved by EPA as the copper SSWQC for Buffalo Creek (Resolve 2015; EPA 2016a).[10] The MLR approach, where shown to be robust and accurate, reduces and sampling and analytical costs significantly as compared to using the full BLM, while still incorporating the BLM's scientific rigor.

EPA has commonly used linear regression to derive its nationally recommended WQC, most of which have been adopted in New Mexico WQS for metals and ammonia. EPA currently uses a simple linear regression with hardness as the independent variable to derive aquatic life criteria for cadmium, chromium, lead, nickel, silver, and zinc. EPA uses a two-parameter linear regression to derive aquatic life criteria for ammonia, using temperature and pH as independent variables. In 2018, EPA used a three-parameter MLR equation (using pH, DOC, and hardness) as the basis for its nationally recommended aquatic life criteria for aluminum (EPA 2018b). EPA is also currently evaluating MLRs as the potential bases of WQC for other metals (EPA 2018a). MLRs have been used by others to describe the effects of water chemistry on the bioavailability and toxicity of metals (EPA 1987; Esbaugh et al. 2012; Fulton and Meyer 2014; Rogevich et al. 2008), including in the development of copper WQC (Brix et al. 2017).

Hence, strong scientific and regulatory rationale exists for using the MLR approach to develop relatively simple equations that account for the effects of water chemistry on metal bioavailability.

[10] The two parameters used for Buffalo Creek were pH and DOC (Resolve 2015).

MLRs can be evaluated by how well they match BLM predictions, a process described in Section 5. An MLR equation that matches copper BLM WQC well yields criteria that are consistent with best available science and with EPA's nationally recommended WQC (EPA 2007a). Using an MLR equation has the benefit of being a transparent and readily available regulatory option that can incorporate EPA (2007a) BLM-based copper WQC into New Mexico WQS as SSWQC for surface waters of the Pajarito Plateau, without the need for BLM software and training.

5 Data Evaluation

This section describes the development of the Pajarito Plateau BLM dataset for the purpose of generating BLM-based copper WQC; it also describes how those data were used to generate an MLR equation for the Pajarito Plateau.

5.1 DQO/DQA Process and BLM Dataset

In 2018, EPA's data quality objective/data quality assessment (DQO/DQA) process was used to select appropriate BLM datasets for several metals (including copper) and determine their usability for performing BLM-based WQC calculations consistent with EPA guidance (Windward 2018b; EPA 2007a).

Both Appendix B to this report and Windward's DQO/DQA (2018b) provide additional information on the DQO/DQA process used to develop a scientifically defensible set of BLM input data. Each step of the 2018 DQO/DQA process pertaining to developing copper BLM inputs is summarized below:

1) **State the problem.** New Mexico's hardness-based copper criteria do not reflect the best available science regarding copper bioavailability and toxicity. Therefore, using the existing copper WQC may lead to erroneous conclusions about whether copper concentrations are protective of aquatic life, as well as erroneous decisions about management actions needed to protect aquatic life.

2) **Define study objectives.** The objectives were to identify and use appropriate data to generate BLM-based criteria for locations on or around the Pajarito Plateau near the Laboratory.

3) **Identify information inputs.** Inputs were sufficiently complete sets of BLM input parameters from discrete water sampling events in surface waters of the Pajarito Plateau. Water chemistry data used for BLM calculations were collected under a defined sampling plan using defensible sampling and analytical methods, QC review, and data validation procedures. The primary source of information for this evaluation was surface water monitoring data collected by LANL (Section 3.4; Appendix A; Appendix B, Section B2).

4) **Define study boundaries**. Temporal boundaries included the time periods over which sufficiently complete BLM input data exist for surface waters of the Pajarito Plateau. Surface water sampling events included either some form of dry weather baseflow (e.g., effluent, springs, and/or snowmelt) or stormflow generated by rainfall. Spatial boundaries included all surface water locations on the Pajarito Plateau in the vicinity of the Laboratory that have sufficient BLM datasets.

5) **Develop an analytical approach.** The overall analytical approach entailed 1) compiling a source dataset from LANL's EIM database, 2) aggregating and evaluating data to determine the extent to which BLM-based criteria can be generated for each discrete event in accordance with available EPA (2007b) guidance (Appendix B, Section B2), and 3) calculating BLM-based "instantaneous criteria" using the EPA (2007a) copper BLM (Section 5.2) for each discrete event with sufficient BLM inputs.

6) **Specify performance and acceptance criteria.** The performance and acceptance criteria for developing an appropriate dataset were primarily based on whether sufficient water chemistry data were available to generate BLM-based WQC for the locations of interest. Specifically, BLM-based calculations were performed only when, at a minimum, pH and organic carbon were measured for the same water sampling event. As appropriate, substitutions or estimations of missing BLM input parameters were conducted as possible from available data, for example using a mathematical relationship between dissolved and total concentrations, substituting the average concentration for a given location, and/or using EPA guidance for such estimations. Acceptance criteria included that 1) samples were collected in ambient surface waters (i.e., within AUs) rather than from storm water runoff locations in developed areas; 2) data used for BLM calculations were validated; and 3) models used for calculations were applicable and defensible for calculating WQC.

7) **Develop a plan for obtaining data**. As discussed in Section 3.4, surface water data, including BLM inputs, have been collected by LANL at many locations since 2005. To perform the analyses described above, water quality data from the EIM database associated with receiving water samples were queried by LANL contractors, and the results were provided to Windward as a spreadsheet. Supplemental water quality data for the Rio Grande were obtained from National Water Quality Monitoring Council's online Water Quality Portal database (National Water Quality Monitoring Council 2019).

The outcome of this process, when applied to LANL's surface water data, was the establishment of a BLM database with sufficient quality and quantity to develop SSWQC for Pajarito Plateau waters and to compare those criteria to existing criteria for copper and other metals. Staff from NMED[11] participated in the review of the DQOs and the 2018 DQO/DQA report.

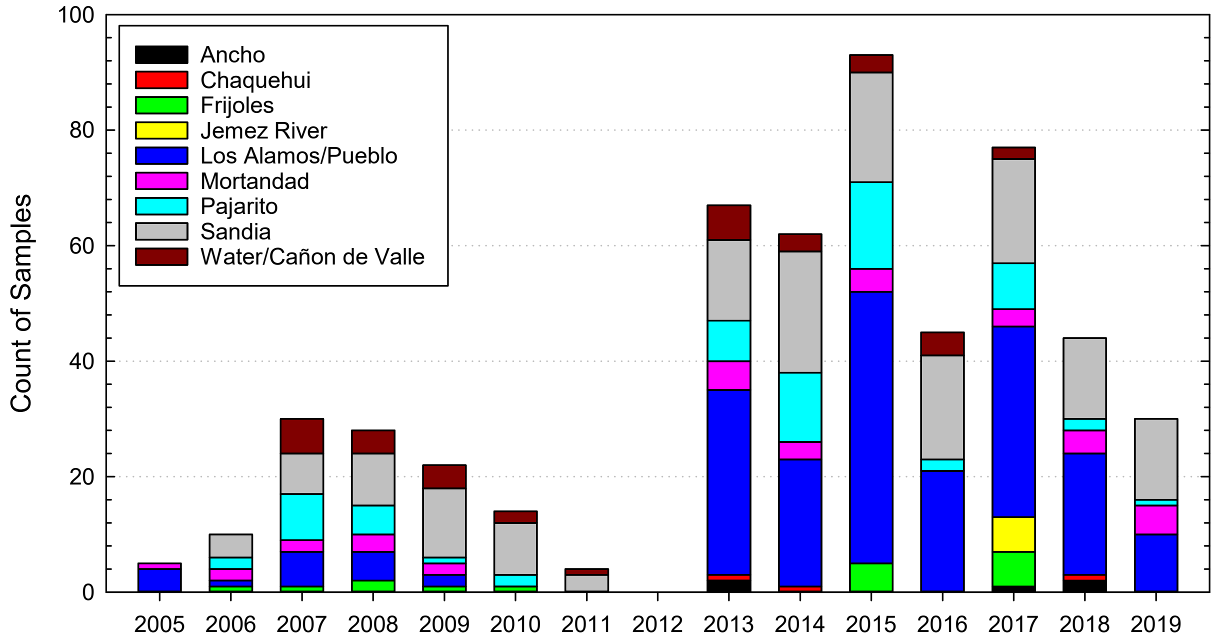
[11] NMED staff from the SWQB and DOE Oversight Bureau participated in kickoff meetings in March 2018, and they submitted comments on the draft DQO/DQA report that were addressed in the April 2018 BLM DQO/DQA report. NMED staff also participated in an October 2018 webinar with EPA Region 6 staff to review and discuss the BLM findings and their potential use as stormwater monitoring TALs for copper, lead, and zinc in the context of the IP.

For this demonstration, the 2018 DQO/DQA process was applied to a water quality dataset that included BLM data collected through 2019 (i.e., two additional years of monitoring data not assessed in the 2018 DQO/DQA report). The complete BLM dataset for the Pajarito Plateau is provided in Appendix A. The source dataset was generated by LANL/N3B (Section 3.4), uploaded to the EIM database, and then exported and provided to Windward by N3B. In addition to analytical data, N3B provided information about sampling locations to support interpretation of the BLM dataset. This information included major and minor watershed names, location classifications related to land use (i.e., undeveloped or downstream of a LANL site), and information on the type of water sample (e.g., surface water, snowmelt, persistent flow, or storm water runoff).

After receiving the source dataset from N3B, Windward aggregated water quality data to establish sufficient input parameters to generate BLM-based copper WQC for each discrete sampling event. Further information on the DQO/DQA process and data aggregation steps used to construct the complete BLM dataset for the Pajarito Plateau is provided in Appendix B (Section B2).

The complete BLM dataset for the Pajarito Plateau spans the period from 2005 to 2019 and includes a total of 531 discrete samples collected from 50 locations across 9 large watersheds.[12] Figure 5-1 shows a breakdown of when and where the 531 BLM samples in the final dataset were collected. Map 3-1 shows each surface water monitoring location. Figures 5-2 and 5-3 show the distributions of water quality parameters in the full dataset (Appendix A).

[12] Ultimately, 517 samples were used for MLR development; 14 samples with pH, DOC, and/or hardness values outside the prescribed ranges for the BLM were removed.



Note: No samples in the final BLM dataset were collected in 2012 due to drought conditions.

Figure 5-1. Distribution of BLM samples by watershed and over time, 2005 to 2019

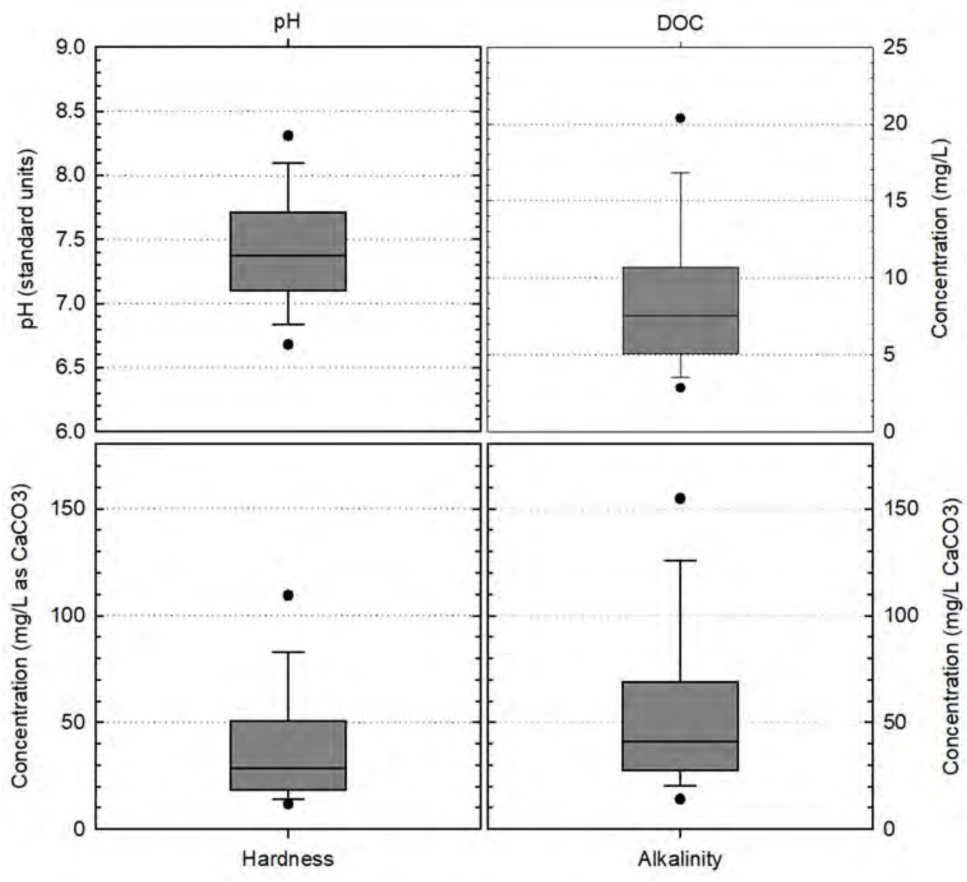
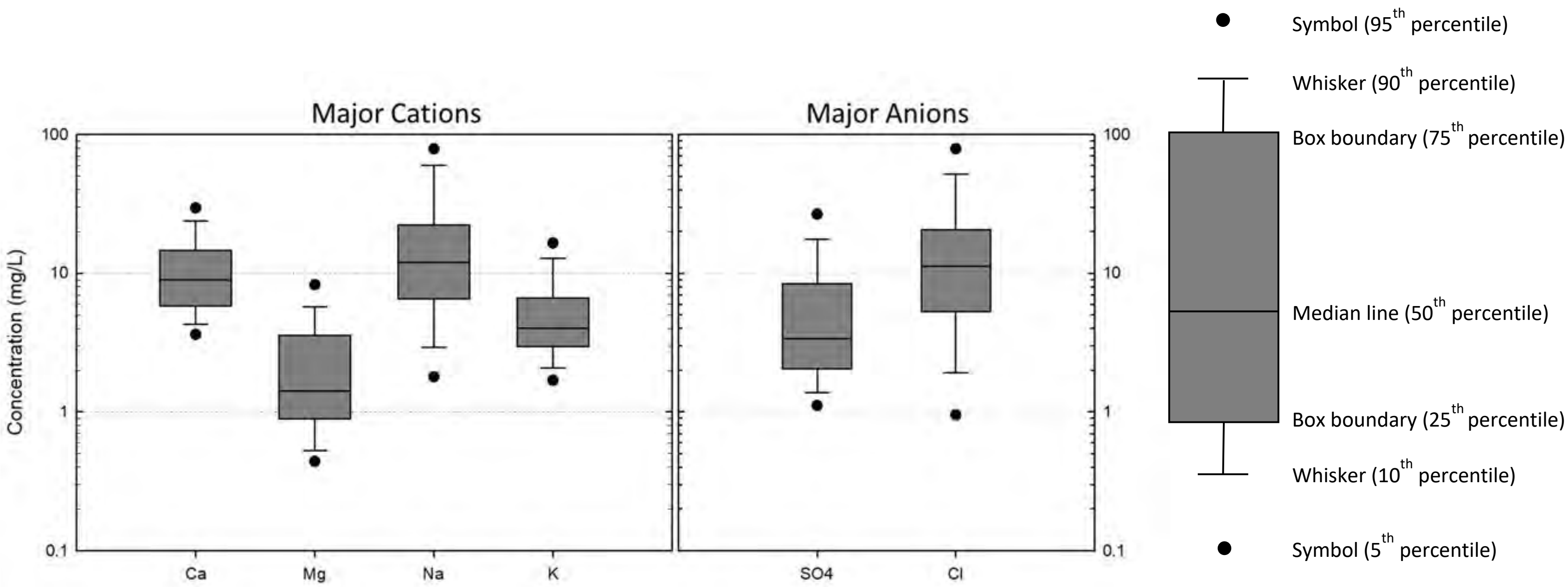


Figure 5-2.Distributions of water quality inputs to the MLR and/or BLM



Note: The following water chemistry parameters are shown: calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), sulfate (SO4), and chloride (Cl).

Figure 5-3.Distributions of major cation and anion inputs to the BLM

As discussed in this report and in Appendix B, hydrology was investigated in detail when developing copper SSWQC, because of the various hydrological classifications of surface waters on the Pajarito Plateau (i.e., ephemeral, intermittent, and perennial). According to New Mexico WQS, chronic and acute WQC apply in specific watersheds based on their respective hydrologic classifications, so the proposed acute and chronic SSWQC, if adopted, would apply similarly. For the purposes of developing and testing MLR equations to accurately estimate BLM WQC, hydrology data were characterized using existing NMAC hydrologic classifications for surface waters of the Pajarito Plateau. Table 5-1 shows a tabular breakdown of samples by major watershed and current NMAC hydrologic classification. Additionally, Appendix B (Section B5.2.3) provides an investigation of potential updated classifications based on the most recent hydrology protocol efforts by NMED and LANL.

Table 5-1. New Mexico WQS hydrologic classification assignments for the BLM dataset by major watershed

Major Watershed	NMAC Hydrological Classification			N by Watershed
	Ephemeral/ Intermittent (20.6.4.128)	Default Intermittent (20.6.4.98)	Perennial (20.6.4.121/ 20.6.4.126)	
Ancho	5	0	0	**5**
Chaquehui	3	0	0	**3**
Frijoles	0	9	8	**17**
Jemez River	0	6	0	**6**
Los Alamos/Pueblo	142	62	0	**204**
Mortandad	28	6	0	**34**
Pajarito	62	0	3	**65**
Sandia	8	0	154	**162**
Water/Cañon de Valle	4	12	19	**35**
N by Hydrology Class	**252**	**95**	**176**	**531**

N – sample size
BLM – biotic ligand model
NMAC – New Mexico Administrative Code
WQS – water quality standard

5.2 BLM Execution

The final BLM dataset (Section 5.1; Appendix A) was input into the copper BLM software (version 3.41.2.45) (Windward 2018a) to generate acute and chronic BLM-based WQC for all samples.[13] These WQC were equivalent to EPA's 2007 copper WQC for freshwater (EPA 2007a) and were used in conjunction with water quality

[13] The most recent BLM software is accessible through the Windward website: https://www.windwardenv.com/biotic-ligand-model.

parameters to develop the copper MLR equations. The reduction of the full suite of BLM parameters to pH, DOC, and hardness for use in the MLR approach is summarized in Sections 5.3 and 5.4.

5.3 BLM Simplification

LANL is proposing MLR equations that will predict BLM-based copper WQC for surface waters of the Pajarito Plateau in the vicinity of the Laboratory. This approach acknowledges both the advantages of the BLM—incorporating the effects of multiple water quality parameters on copper bioavailability and toxicity—and the challenges—measuring BLM parameters across a large area with a range of water quality and flow conditions. Estimating BLM copper WQC accurately using fewer parameters than the full list of 12 inputs will facilitate copper evaluations.

As described in Section 5.1, site-specific water quality data were collated from 531 samples from 50 locations from 2005 to 2019 (Appendix A). A set of 517 samples spanning 8 watersheds[14] was carried forward to the first round of MLR modeling; 14 samples were removed due to DOC, hardness, or pH concentrations outside of the prescribed ranges (Table 5-2) for the BLM. Thus, the water quality conditions in Pajarito Plateau surface water samples spanned the entire range of conditions considered reasonable for use in the copper BLM. Modeling methods are summarized in Section 5.4.1 and detailed in Appendix B.

Table 5-2. Prescribed ranges for BLM input parameters

BLM Parameter	BLM Prescribed Range	
	Minimum	Maximum
DOC	0.05	29.65
Hardness	7.9	525
pH	4.9	9.2

Source: Windward (2019)

BLM – biotic ligand model

DOC – dissolved organic carbon

Table 5-3 presents the results of a Spearman correlation analysis (i.e., Spearman rho values) that further substantiate the importance of pH, DOC, and hardness in calculating BLM-based criteria for the Pajarito Plateau. This table illustrates correlations among the three parameters and other BLM input parameters.

[14] The six samples from the Jemez River watershed (Table 5-1) were not carried forward to the MLR analysis because hardness concentrations were < 7.9 mg/L as calcium carbonate (the minimum prescribed concentration for the BLM). Thus, the number of watersheds in the MLR dataset was eight, not nine.

Table 5-3. Spearman correlation analysis results (rho)

Parameter	BLM CMC	BLM CCC	pH	DOC	Hardness	Calcium	Magnesium	Sodium	Potassium	Sulfate	Chloride	Alkalinity
BLM CMC	--	--	0.57	0.54	0.42	0.41	0.43	0.38	0.57	0.45	0.36	0.55
BLM CCC	--	--	0.57	0.54	0.42	0.41	0.43	0.38	0.57	0.45	0.36	0.55
pH	0.57	0.57	--	-0.29	0.57	0.57	0.53	0.5	0.36	0.5	0.44	0.66
DOC	0.54	0.54	-0.29	--	-0.09	-0.09	ns	-0.17	0.23	ns	-0.14	ns
Hardness	0.42	0.42	0.57	-0.09	--	0.99	0.92	0.63	0.63	0.73	0.54	0.83
Calcium	0.41	0.41	0.57	-0.09	0.99	--	0.86	0.6	0.6	0.69	0.52	0.82
Magnesium	0.43	0.43	0.53	ns	0.92	0.86	--	0.64	0.71	0.78	0.55	0.8
Sodium	0.38	0.38	0.5	-0.17	0.63	0.6	0.64	--	0.7	0.8	0.91	0.62
Potassium	0.57	0.57	0.36	0.23	0.63	0.6	0.71	0.7	--	0.72	0.61	0.66
Sulfate	0.45	0.45	0.5	ns	0.73	0.69	0.78	0.8	0.72	--	0.76	0.68
Chloride	0.36	0.36	0.44	-0.14	0.54	0.52	0.55	0.91	0.61	0.76	--	0.54
Alkalinity	0.55	0.55	0.66	ns	0.83	0.82	0.8	0.62	0.66	0.68	0.54	--

Note: All values are Spearman correlation coefficients, which can range from -1 to 1. Only significant correlations are reported (alpha = 0.05); color shading indicates relative strength of correlation (with blue being positive values and red being negative). BLM CMC and CCC correlations are identical because the acute and chronic BLM values differ only by an acute-to-chronic ratio.

BLM – biotic ligand model

CMC – criterion maximum concentration

CCC – criterion continuous concentration

DOC – dissolved organic carbon

ns – not significant

Table 5-3 shows that the strongest correlations with BLM output (i.e., CMC and CCC) are for pH (rho = 0.57), potassium (rho = 0.57), alkalinity (rho = 0.55), and DOC (rho = 0.54). Thus, pH and DOC are reasonable to retain for a simplified model, because they have relatively strong correlations and are well supported by the literature regarding mechanisms affecting copper bioavailability (i.e., copper speciation and complexation). While hardness is marginally less correlated with BLM output (rho = 0.44) than are other parameters, hardness is significantly correlated ($p < 0.05$) with pH, calcium, magnesium, sodium, potassium, sulfate, chloride, and alkalinity. Consequently, including hardness in the simplified version incorporates the influence of these parameters on BLM output and builds upon New Mexico's current hardness-based copper criteria in response to which LANL has already collected a substantial amount of hardness data.

While potassium is relatively correlated with the BLM output, it is not as mechanistically significant as pH, DOC, or hardness, based on sensitivity analyses of the copper BLM.[15] In their development of a copper BLM specific to the cladoceran *Daphnia magna*, De Schamphelaere and Janssen (2002) evaluated the influence of calcium, magnesium, sodium, potassium, and pH and found that potassium was the only parameter considered that did not affect toxicity. Brix et al. (2017) found that MLR models using only pH, DOC, and hardness (without other parameters) predicted copper toxicity values with a level of accuracy comparable to that of the copper BLM. From a statistical standpoint, it is beneficial to develop parsimonious models rather than to include many intercorrelated variables, which can result in "overfitting."[16] Therefore, the importance of potassium for modeling BLM output was viewed skeptically when developing MLRs.

5.4 MLR Equation Development

This section describes the development of acute and chronic MLR equations using BLM input parameter data and corresponding BLM outputs (i.e., BLM-based WQC). For the MLR evaluations, DOC and hardness were transformed using the natural logarithm. This transformation was not required for pH, since it is already on a logarithmic scale. The evaluations were conducted primarily for the acute BLM-based WQC, because EPA (2007a) applies an acute-to-chronic ratio to generate chronic BLM-based WQC. As a result, the acute and chronic BLM WQC for copper vary by a constant factor (i.e., 1.61), regardless of water chemistry. Therefore, the following evaluations regarding the development of a best-fit MLR equation are applicable to both acute and chronic copper WQC.

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[15] Personal communication, Robert Santore (developer of the copper BLM software).

[16] An overfitted MLR will generally predict the underlying dataset better than a simpler model, but it is less likely to predict future data with similar accuracy. Overfit models are overly specific.

5.4.1 Methods

Many candidate MLRs were developed, evaluated, and compared using standard statistical and visual methods, which included statistics related to each model's goodness-of-fit (e.g., adjusted R^2) and model assumptions (e.g., tests of the normality and homoscedasticity of residuals). Visual tools were used to evaluate model fit and to facilitate model refinements (Appendix B, Section B4).

The development of models followed several general steps iterated over several rounds of modeling. First, a basic model was tested that contained only pH, DOC, and hardness, consistent with previously developed MLR models (Brix et al. 2017) and the simplified BLM (Windward 2019). These three water quality parameters affect copper speciation (e.g., pH), complexation with the free cupric ion ($copper^{2+}$) (e.g., DOC), and competition with copper at a site of uptake by the organism (e.g., $calcium^{2+}$ represented by hardness and $hydrogen^{+}$ represented by pH). As such, they capture the primary mechanisms affecting copper bioavailability that underpin the copper BLM.

Once this baseline model was established, various other, more complex models that included additional parameters were developed. For example, models included different slopes and/or intercepts for ephemeral/intermittent, intermittent, and perennial NMAC classifications. The development of these models was followed by a stepwise regression step, wherein the statistical software was allowed to test many permutations of the larger model by adding or removing the hydrologic slopes and intercepts and checking the goodness-of-fit of each permutation.[17] This step provided information about which of the variables in the most complex model might be important and which could be excluded during the model refinement step. The final step, model refinement, involved both the removal of unimportant variables and the addition of a new variable, squared pH (pH^2), to eliminate patterns observed in the model residuals (Figure 5-4).

5.4.2 Results

A detailed discussion of the development of MLR equations is provided in Appendix B, Section B4. This section provides a summary of those findings and the stepwise MLR analyses that led to the proposed MLR equations for copper SSWQC.

As noted in Section 5.4.1, MLRs were developed over several rounds. The first round started with a simple model using pH, DOC, and hardness as the independent variables to predict BLM-based WQC. This model resulted in a very high adjusted R^2 of 0.969, indicating that 96.9% of the variation in BLM-based WQC can be accounted for by these three parameters.

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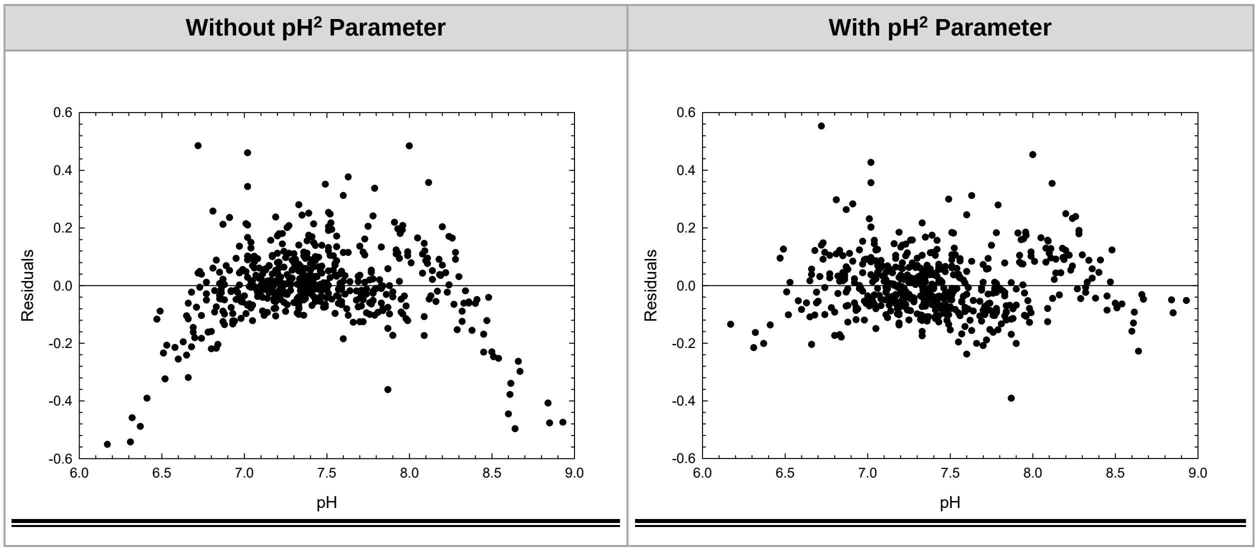
[17] This step was limited to hydrological classification parameters, slopes, and intercepts. DOC, pH, and hardness were retained throughout the stepwise analysis.

More complex models including pH, DOC, and hardness, as well as hydrology-specific slopes and intercepts for the ephemeral/intermittent, intermittent, and perennial classifications, were considered in the second round. While evaluating this model structure, it was observed that MLR model residuals (i.e., difference between BLM WQC and MLR-predicted WQC) and pH had a curvilinear relationship (Figure 5-4, left panel). To address this, a pH^2 term was added to the model in the third round; this eliminated the curvilinear pattern in residuals (Figure 5-4, right panel).



Note: Horizontal line at a residual of zero indicates perfect prediction.

Figure 5-4. Comparison of MLR model residuals with and without a pH^2 parameter

After including the pH^2 term, models without hydrology factors were also developed as part of the third round of modeling. Comparisons of summary statistics among these various models (Table 5-4), analysis of residuals (Appendix B, Section B4), and consideration of the magnitudes of differences among models led to the conclusion that the use of hydrology-specific slopes and intercepts did not result in better MLR equations compared to the use of less complex (i.e., more parsimonious) models. For example, after removing all hydrological classification parameters from the MLR in the third round of modeling, the adjusted R^2 changed from 0.983 to 0.980, meaning that hydrology classification explained only 0.3% of the variation not already explained by pH, DOC, and hardness. From a practical standpoint, the added complexity of hydrological classification was not needed to accurately predict BLM-based copper WQC. Moreover, because the NMAC classes are subject to change over time (e.g., default intermittent waters are potentially reclassified through the hydrology protocol process), to include hydrologic classification could lead to unnecessary ambiguity in future applications of the MLR.

Table 5-4. Summary statistics of MLR models fit to BLM-based WQC

Model Description	Development Method[a]	Adjusted R^2	Predicted R^2	AIC	BIC	Shapiro-Wilk Test p-value[b]	Scores Test p-value[c]
Simplest model; includes pH, DOC, and hardness only (no distinction in hydrology)	full	0.969	0.968	-614	-593	<0.001	0.249
Hydrology slopes and intercepts	full	0.973	0.971	-677	-621	<0.001	0.751
	AIC	0.973	0.971	-681	-643	<0.001	0.704
	BIC	0.973	0.971	-681	-643	<0.001	0.704
Hydrology slopes and intercepts; pH^2 added	full	0.984	0.981	-928	-860	<0.001	0.0476
	AIC	0.984	0.981	-928	-860	<0.001	0.0476
	BIC	0.983	0.981	-918	-876	<0.001	0.00332
Hydrology intercepts only (slopes excluded); pH^2 term always included	full	0.982	0.982	-899	-865	<0.001	0.0204
	AIC	0.982	0.982	-899	-865	<0.001	0.0204
	BIC	0.982	0.982	-899	-865	<0.001	0.0204
No distinction in hydrology; pH^2 term always included; final models (proposed MLRs for copper SSWQC)	full (acute)	0.980	0.979	-833	-808	<0.001	0.083
	full (chronic)	0.980	0.979	-833	-808	<0.001	0.083

[a] Development methods are divided into "full" models (includes all variables indicated in model description) or AIC/BIC stepwise regression models.

[b] Shapiro-Wilk test for normality of residuals; $p < 0.05$ indicates non-normality.

[c] Scores test for homogeneity of residuals; $p < 0.05$ indicates non-constant variance (i.e., heteroscedasticity).

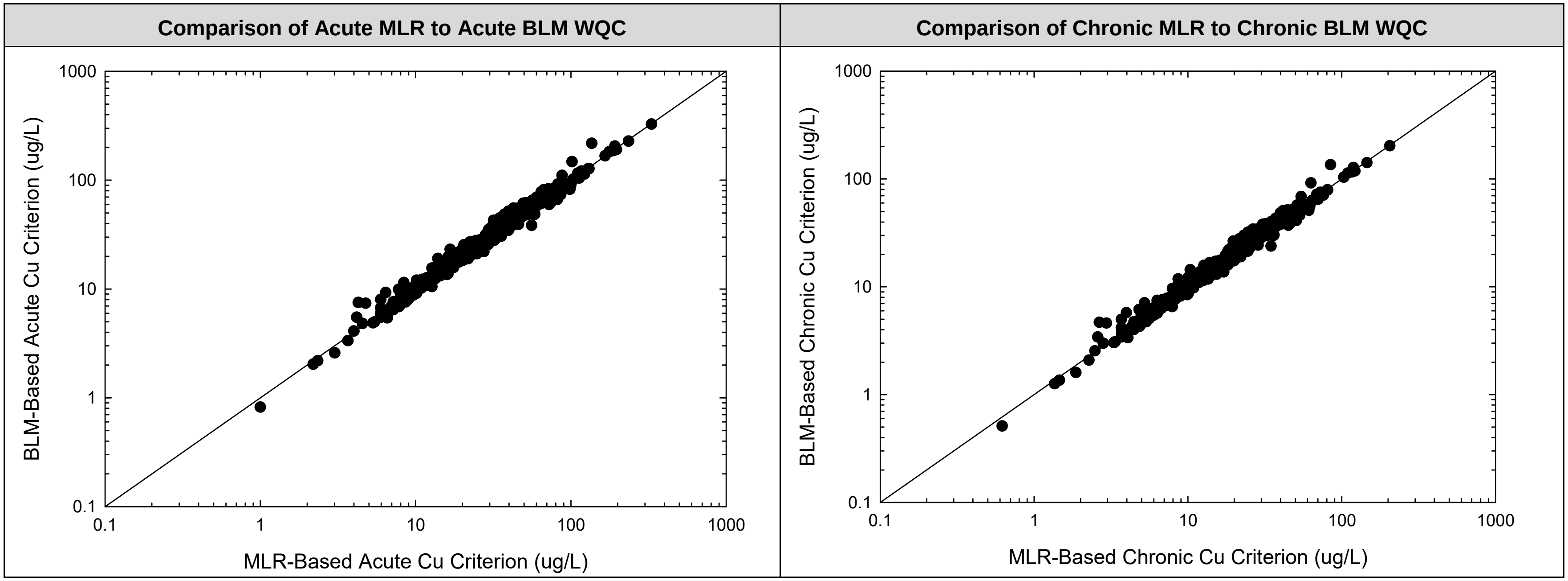
AIC – Akaike's Information Criterion
BIC – Bayesian Information Criterion
BLM – biotic ligand model
DOC – dissolved organic carbon
MLR – multiple linear regression
SSWQC – site-specific water quality criterion
WQC – water quality criterion

After demonstrating that an MLR model including hydrological class is not a substantial improvement over a more parsimonious model, and after including a pH^2 parameter to address residual patterns, Equations 1 and 2 were selected to predict dissolved acute and chronic BLM-based copper WQC, respectively. These equations are proposed as SSWQC.

$$\boldsymbol{CMC = exp(-22.914 + 1.017 \times ln(DOC) + 0.045 \times ln(hardness) + 5.176 \times pH - 0.261 \times pH^2)} \quad \textbf{Equation 1}$$

$$\boldsymbol{CCC = \exp(-23.391 + 1.017 \times ln(DOC) + 0.045 \times ln(hardness) + 5.176 \times pH - 0.261 \times pH^2)} \quad \textbf{Equation 2}$$

Figure 5-5 shows comparisons of MLR-based WQC calculations to BLM-based copper WQC for the Pajarito Plateau BLM dataset. The figure shows that copper WQC are very similar between the two approaches (adjusted $R^2 = 0.980$ for the acute and chronic MLRs) and values are distributed evenly across the solid diagonal 1:1 line representing perfect agreement. Therefore, the three-parameter MLR equations provide highly accurate results. In addition, more points fall above the 1:1 line (n = 261) than below (n = 256) in Figure 5-5, indicating that overall, the proposed copper SSWQC equations provide more conservative copper WQC for the Pajarito Plateau than the BLM software.

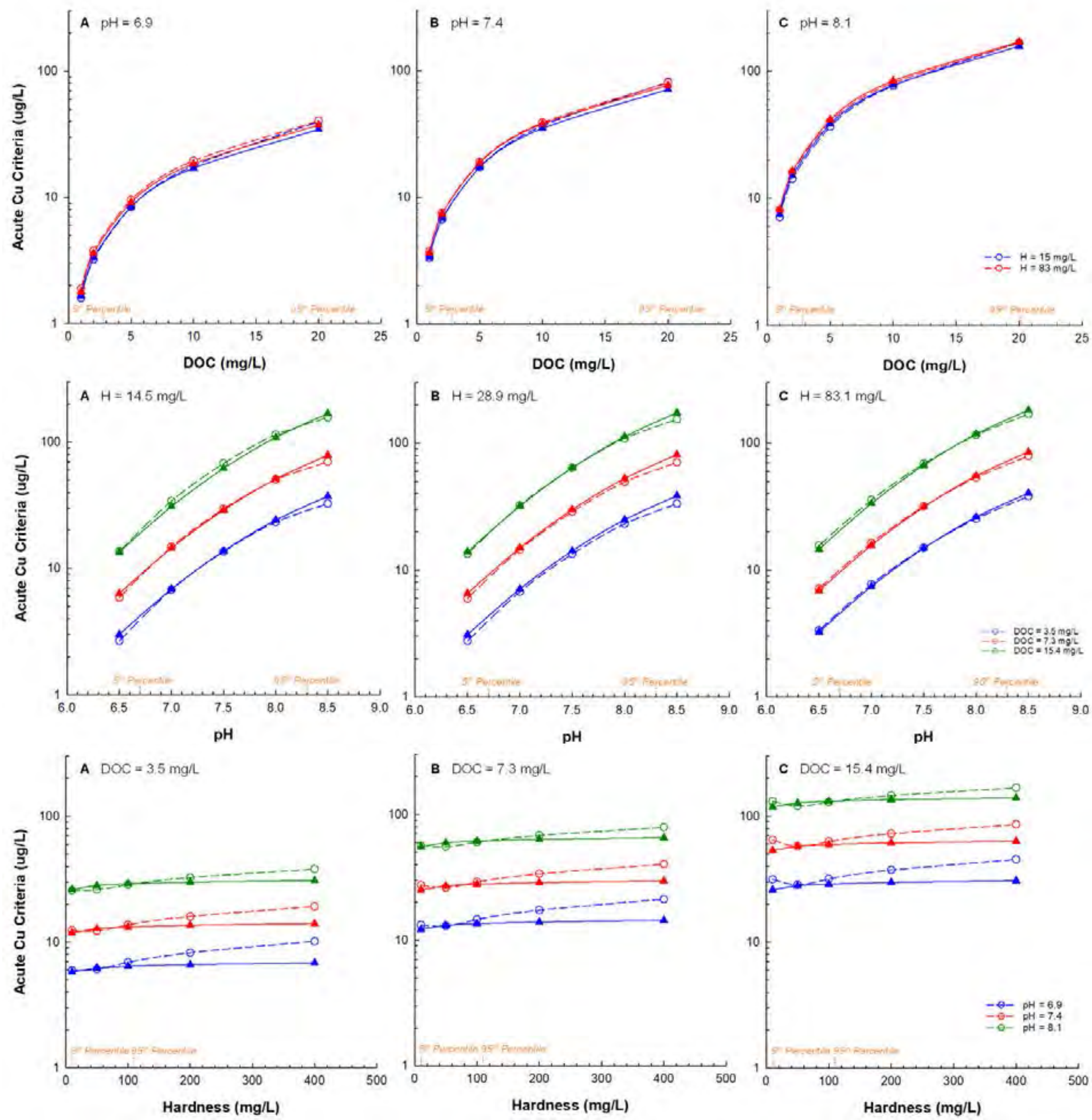


Note: Solid line represents a 1:1 relationship (perfect agreement).

N = 517 samples (BLM dataset for the Pajarito Plateau excluding samples outside the BLM prescribed ranges for pH, DOC, and hardness)

Figure 5-5.Comparison of proposed acute and chronic copper SSWQC predictions to acute and chronic BLM WQC

Figure 5-6 presents an additional comparison of MLR- and BLM-based copper WQC across varying concentrations and combinations of DOC, pH, and hardness.



Note: BLM-based criteria are shown as dashed lines and open circles. MLR-based acute criteria are shown as solid lines and triangles. Blue, red, and green plots represent the 10th, 50th, and 90th percentiles, respectively, in the BLM dataset for the Pajarito Plateau. The 5th and 95th percentiles for each parameter are shown in orange on each x-axis. For comparative purposes, BLM criteria were generated with the "simplified site chemistry" input option using median ion ratios in the site-specific dataset.

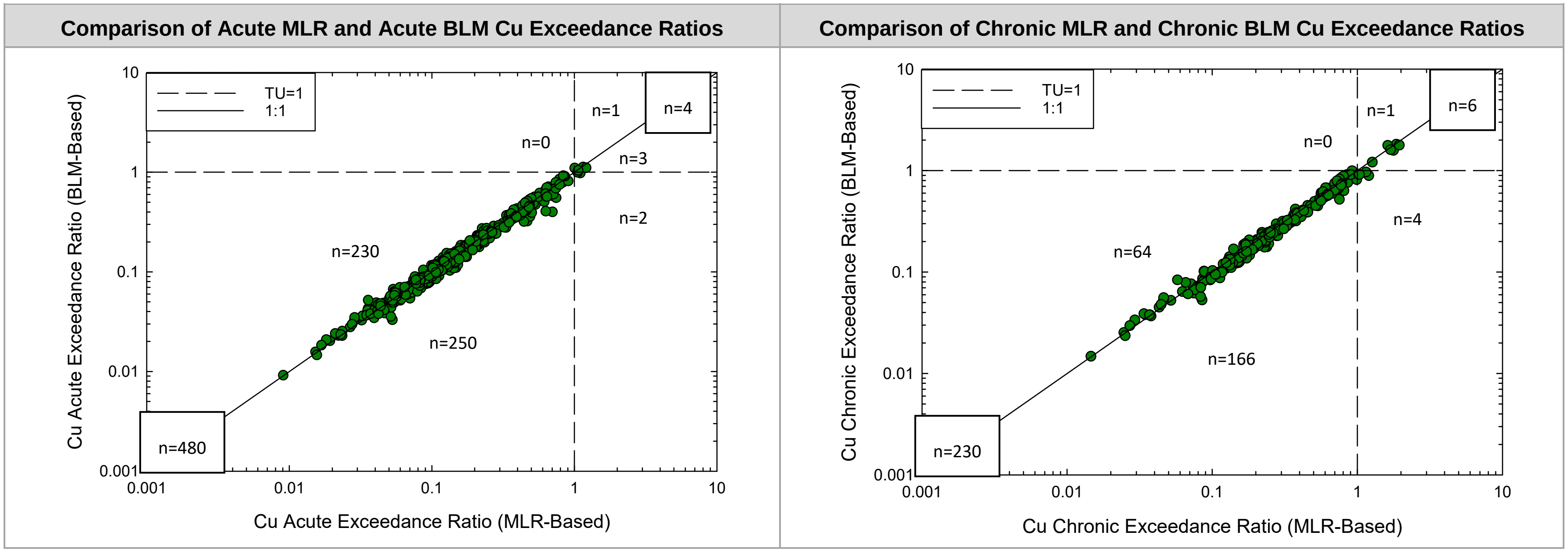
Figure 5-6. Comparison of BLM- and MLR-based acute criteria

Figure 5-6 shows how the MLR- and BLM-based copper WQC vary as a function of DOC (top row), pH (middle row), and hardness (bottom row). For comparative purposes, MLR- and BLM-based copper WQC were generated using various combinations of DOC, pH, and hardness concentrations corresponding to the 10th, 50th, and 90th percentiles in the BLM dataset for the Pajarito Plateau (shown as the colored lines and panels A, B, and C in Figure 5-6). This comparison further demonstrates the consistency between MLR-based copper WQC (solid lines, triangles) and BLM-based copper WQC (dashed lines, open circles) across a wide range of water chemistries. The greatest deviation between the two approaches occurs at high-hardness concentrations (≥ 200 mg/L); however, BLM-based copper WQC are greater than MLR-based copper WQC, indicating that the proposed MLR-based copper WQC are conservative under high-hardness conditions. Furthermore, such conditions are uncommon in surface waters on the Pajarito Plateau, as indicated by the 5th and 95th percentiles shown on the x-axes in Figure 5-6. Overall, the high degree of consistency between BLM- and MLR-based WQC over the range of water chemistries observed throughout the Pajarito Plateau indicates that the proposed MLR equations provide a reliable and scientifically defensible method to accurately estimate EPA's (2007a) nationally recommended copper WQC on a site-specific basis. Appendix B provides additional evaluations of the proposed MLR equations that further substantiate their selection as proposed copper SSWQC.

5.5 Comparison to Current Copper WQC

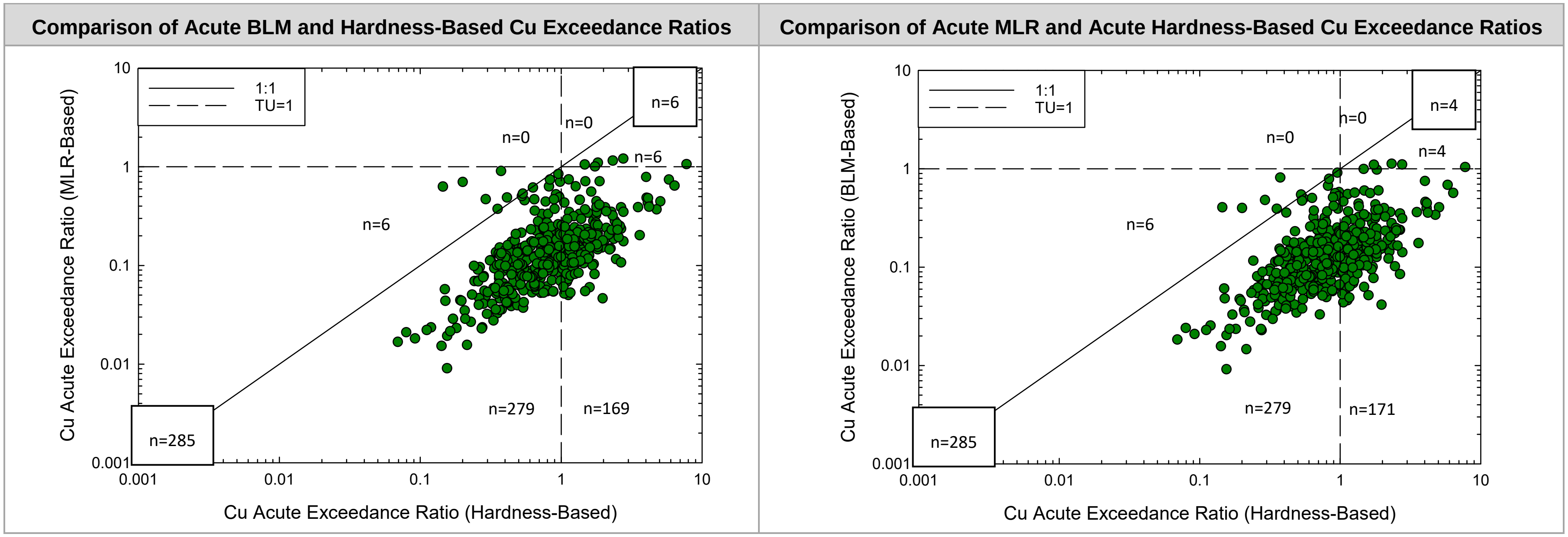
Comparisons of copper exceedance ratios[18] calculated using EPA's (2007a) BLM, the site-specific MLR (Equation 1), and New Mexico's current hardness-based WQC are shown in Figures 5-7 through 5-10. Figure 5-7 compares exceedance ratios for the acute and chronic BLM- and MLR-based criteria. Figure 5-8a compares acute exceedance ratios for the BLM- and MLR-based criteria to acute hardness-based criteria, and Figure 5-8b presents the same comparison for exceedance ratios of the analogous chronic criteria. Figures 5-9 and 5-10 present similar results as boxplots (showing results by watershed) for the acute and chronic criteria, respectively.

[18] Exceedance ratio = measured copper concentration divided by copper WQC.



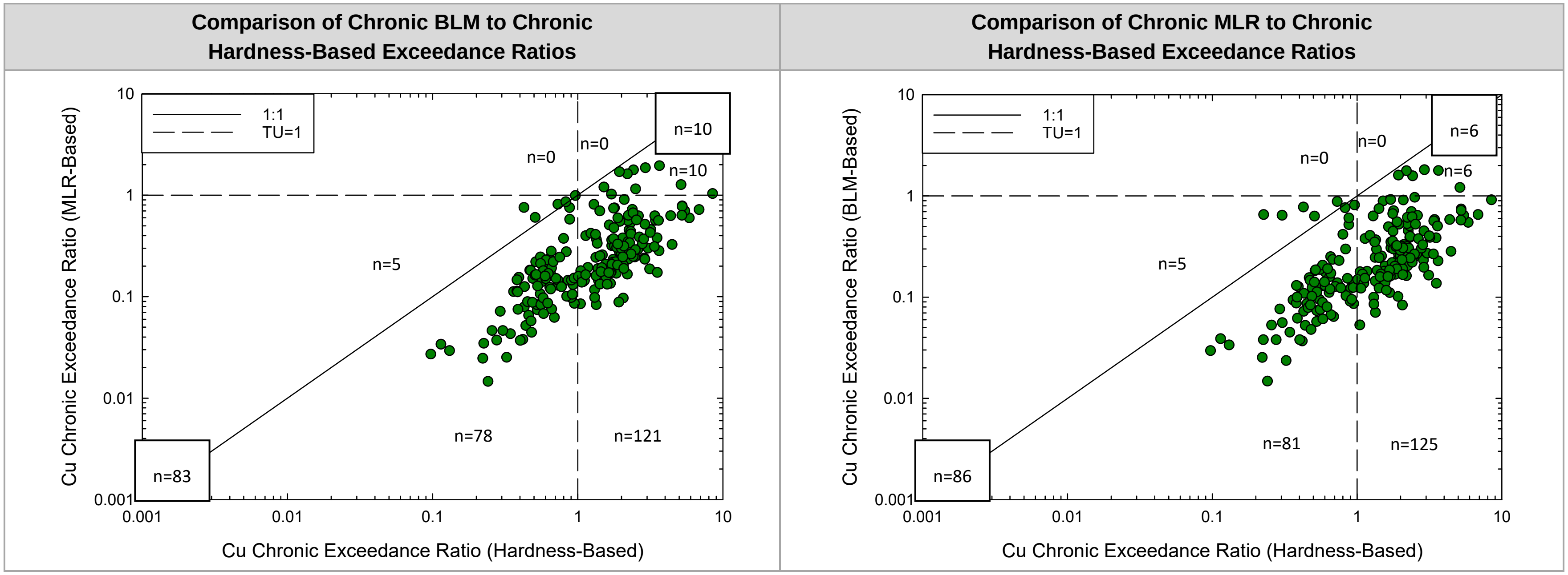
Note: Copper exceedance ratios are measured dissolved copper concentrations divided by a copper criterion. The solid 1:1 line represents perfect agreement between two criteria, and the dashed lines indicate the points at which copper concentrations exceed each criterion. “N” sample sizes represent the counts of samples in subareas of the plot defined by the solid and dashed lines. The “N” values in boxes represent the sums of samples in either the upper right or lower left quadrant, where there is general agreement between the two criteria (i.e., both predict an exceedance or non-exceedance of a copper criterion). The chronic exceedance ratio plot on the right excludes samples collected from locations classified under 20.6.4.128 NMAC in which only the acute criteria apply. Plots exclude samples in the Pajarito Plateau BLM dataset where copper detection limits were greater than BLM-based WQC.

Figure 5-7.Comparison of copper exceedance ratios between EPA (2007) BLM WQC and site-specific MLR WQC



Note: Copper exceedance ratios are measured dissolved copper concentrations divided by a copper criterion. The solid 1:1 line represents perfect agreement between two criteria, and the dashed lines indicate the points at which copper concentrations exceed each criterion. “N” sample sizes represent the count of samples in subareas of the plot defined by the solid and dashed lines. The “N” values in boxes represent the sums of samples in either the upper right or lower left quadrant, where there is general agreement between the two criteria (i.e., both predict an exceedance or non-exceedance of a copper criterion). Plots exclude samples in the Pajarito Plateau BLM dataset, where copper detection limits were greater than BLM-based or hardness-based WQC.

Figure 5-8a. Comparison of acute copper exceedance ratios between EPA (2007) BLM WQC or site-specific copper MLR WQC and New Mexico hardness-based WQC



Note: Copper exceedance ratios are measured dissolved copper concentrations divided by a copper criterion. The solid 1:1 line represents perfect agreement between two criteria, and the dashed lines indicate the points at which copper concentrations exceed each criterion. “N” sample sizes represent the count of samples in subareas of the plot defined by the solid and dashed lines. The “N” values in boxes represent the sums of samples in either the upper right or lower left quadrant, where there is general agreement between the two criteria (i.e., both predict an exceedance or non-exceedance of a copper criterion). Plots exclude samples in the Pajarito Plateau BLM dataset, where copper detection limits were greater than BLM-based or hardness-based WQC and samples collected from locations classified under 20.6.4.128 NMAC in which acute only criteria applies.

Figure 5-8b. Comparison of chronic copper exceedance ratios between EPA (2007) BLM WQC or site-specific copper MLR WQC and New Mexico hardness-based WQC

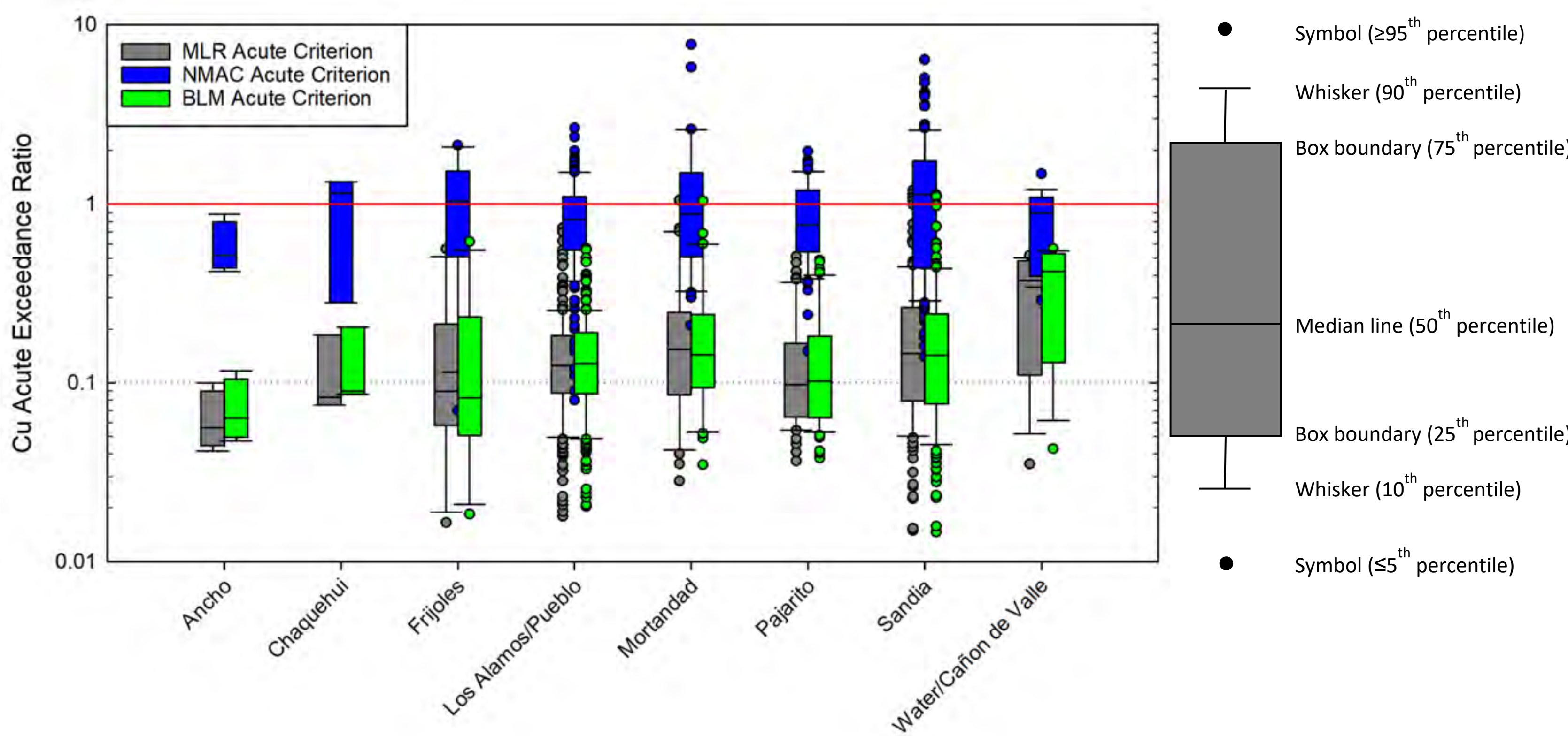


Figure 5-9. Acute copper exceedance ratios for EPA (2007) BLM, site-specific MLR, and New Mexico hardness-based WQC for major watersheds on the Pajarito Plateau

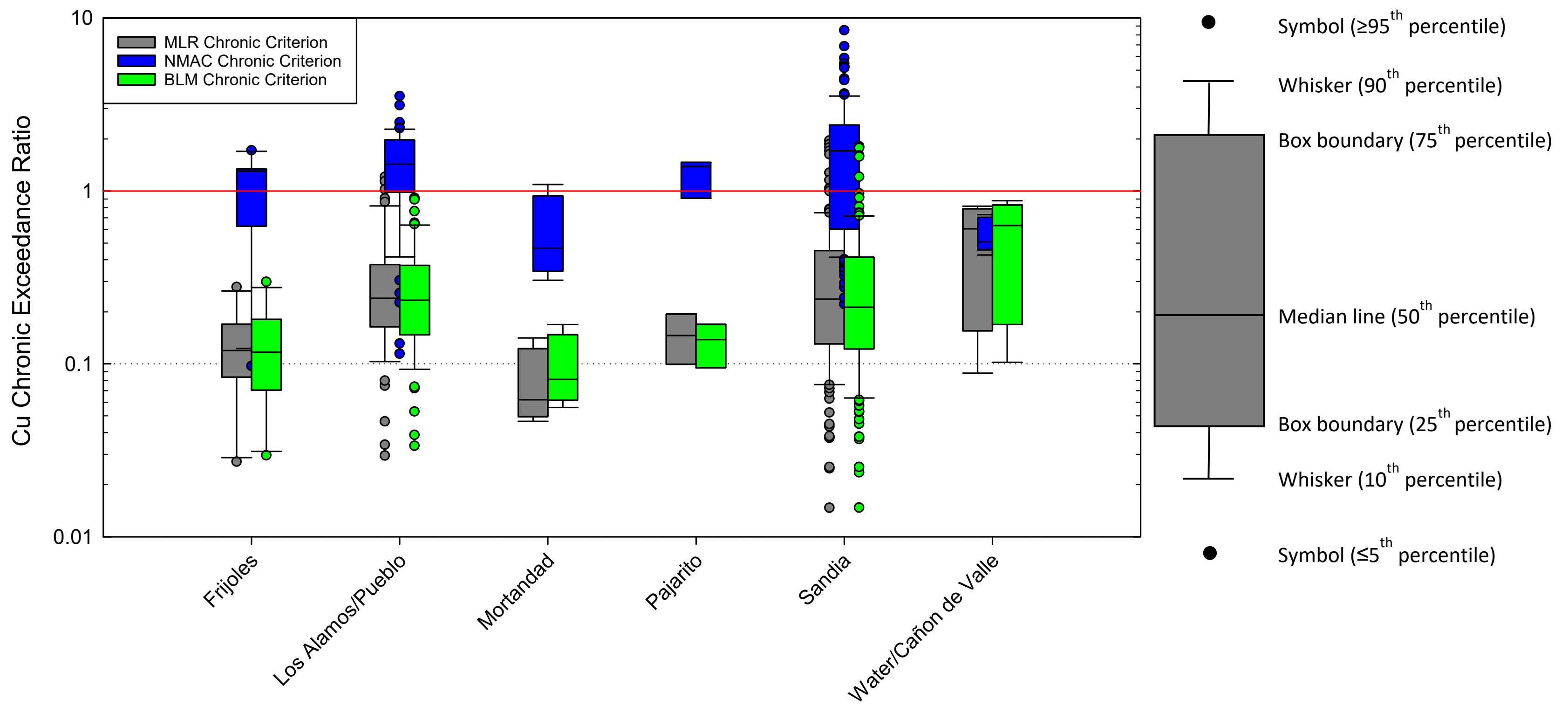


Figure 5-10. Chronic copper exceedance ratios for EPA (2007) BLM, site-specific MLR, and New Mexico hardness-based WQC for major watersheds on the Pajarito Plateau

Several conclusions can be drawn based on these comparisons. First, the frequency and magnitude with which copper concentrations exceed either BLM- or MLR-based acute WQC are very similar. For example, four exceedances of the acute BLM WQC and six exceedances of the acute MLR WQC and six exceedances of the chronic BLM WQC and 10 exceedances of the chronic MLR WQC were observed in the final DQO dataset (i.e., points above the horizontal dashed line or right of the vertical dashed line, respectively, in Figure 5-7).[19] The magnitude of these exceedances was low (i.e., acute exceedance ratios < 1.2 and chronic exceedance ratios < 2.0 for both models). Figure 5-7 also shows that exceedance ratios are highly correlated and distributed evenly around the solid diagonal 1:1 line (representing perfect agreement), again reflecting the high accuracy with which the MLR equations generate BLM software-based criteria.

Differences in exceedance frequencies between hardness-based WQC and BLM- or MLR-based WQC were substantial (e.g., n = 175 points to the right of the vertical dashed lines in Figure 5-8a and n = 131 points to the right of the vertical dashed lines in Figure 5-8b). Spatially, these hardness-based WQC exceedances occurred across most of the major Pajarito Plateau watersheds (Figure 5-9).

Finally, the differences observed between the hardness-based exceedance ratios and those calculated using either the BLM or MLR reflect the strong influence of water chemistry parameters other than hardness (e.g., pH and DOC) on the bioavailability and toxicity of copper. Consequently, continued application of the current hardness-based copper WQC is likely to lead to inaccurate and unnecessary regulatory actions (e.g., 303[d] listings and TMDLs), given that the MLR-based copper WQC are based on the best available science and provide a more accurate level of protection in accordance with EPA (1985, 2007a) recommendations.

5.6 CONSIDERATION OF DOWNSTREAM RIO GRANDE WATERS

The SSWQC proposed in this report would apply to waters flowing into the Rio Grande from the Pajarito Plateau but not to waters of the Rio Grande. Potential impacts of the SSWQC on downstream waters in the Rio Grande were evaluated and found to be absent.

Rio Grande water quality data collected by the United States Geological Survey (USGS) were obtained from the National Water Quality Monitoring Council (2019) and were then input into the copper SSWQC equations and New Mexico's hardness-based copper criteria equations. Figure 5-11 shows available copper concentrations measured at USGS gaging stations on the Rio Grande from 2005 to 2021.[20] Copper

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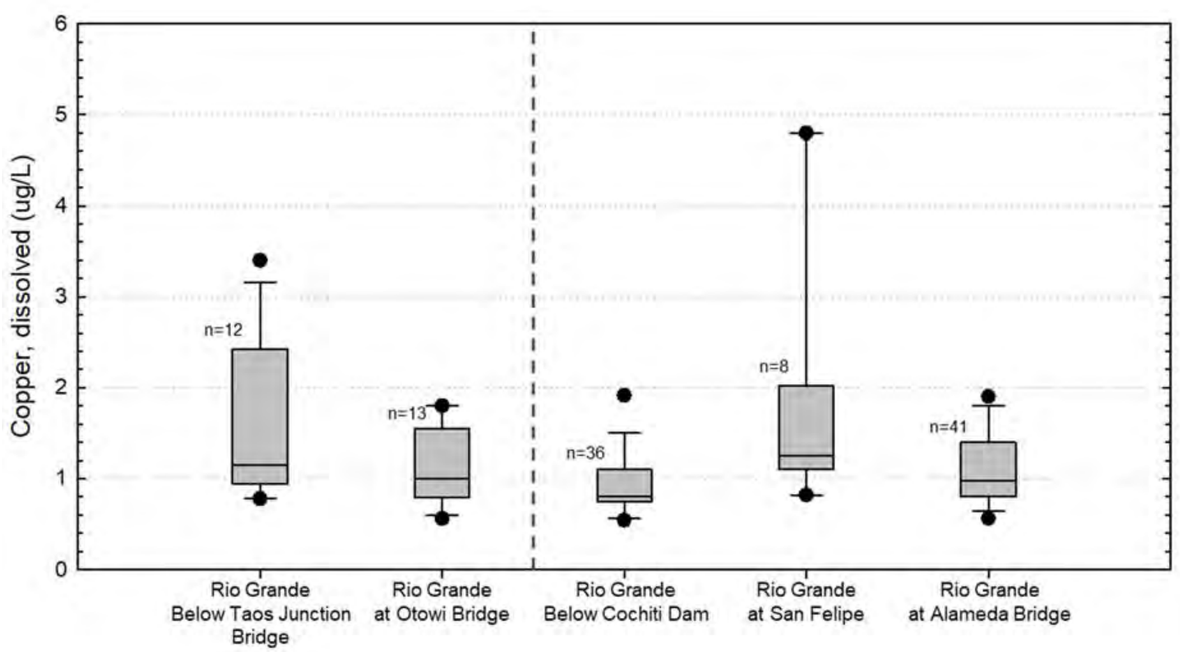
[19] Figures 5-7 to 5-9 exclude samples with non-detect copper concentrations exceeding the BLM-based copper WQC.

[20] Rio Grande data used for this evaluation are also presented in Appendix D (Table D-1).

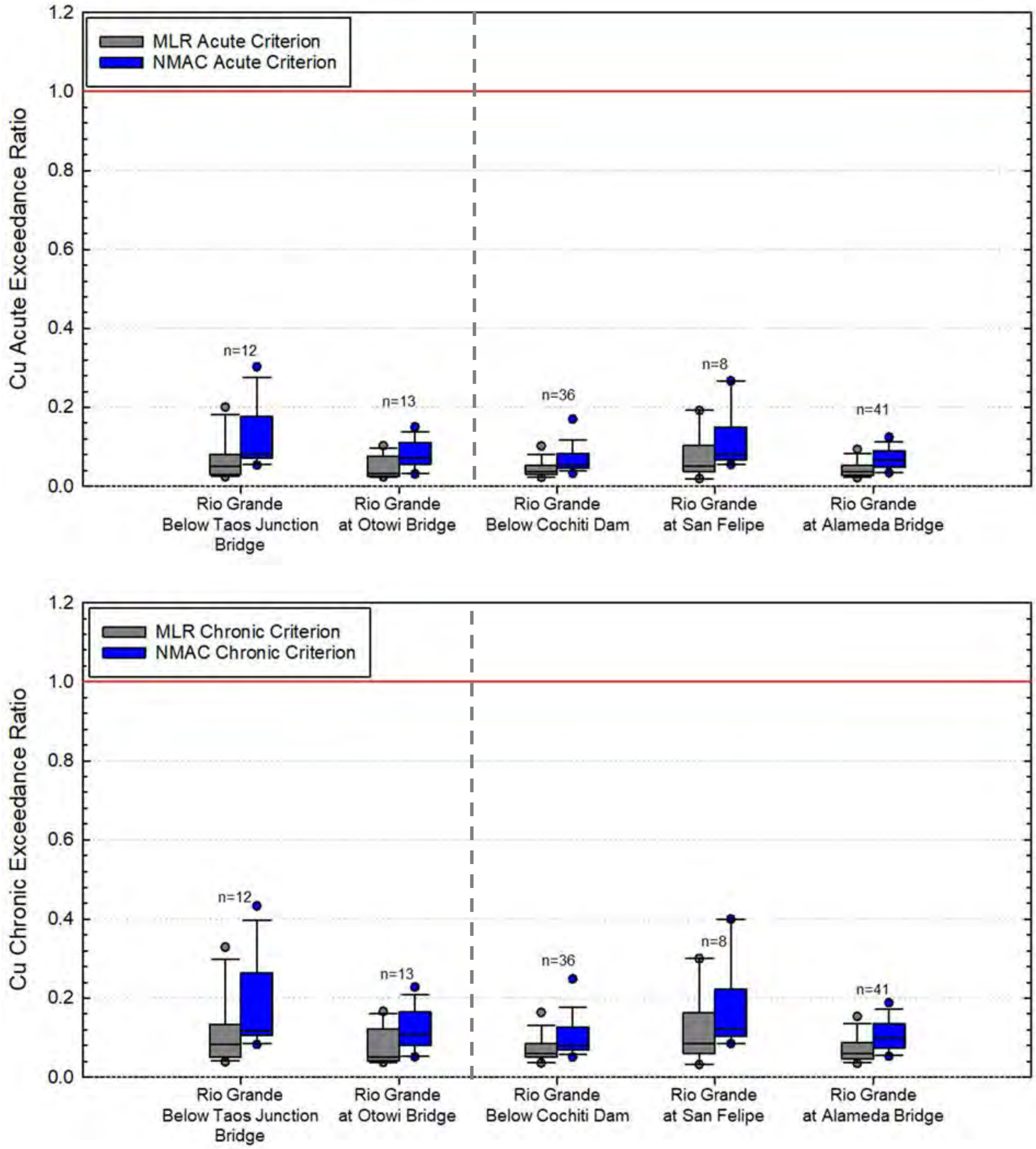
concentrations in the Rio Grande upstream and downstream of confluences with Pajarito Plateau tributaries are low and stable, and no samples contained copper concentrations in excess of either the hardness-based criteria or the BLM-based SSWQC (Figure 5-12). This finding is also consistent with the lack of 303(d) listings for copper in the Rio Grande in the vicinity (upstream and downstream) of the Laboratory. The two AUs of the Rio Grande above and three AUs below confluences with Pajarito Plateau tributaries have not been listed as impaired due to copper in New Mexico's 303(d)/305(b) IRs available on NMED's webpage (NMED 2021), which includes listings for the 2008-2010 IR through the draft 2022-2024 IR cycles. It is also notable that copper concentrations in the Rio Grande are comparable to or less than copper background threshold values (BTVs) derived for undeveloped conditions on the Pajarito Plateau (3.12 µg/L) and substantially less than BTVs for developed conditions (urban runoff) unrelated to LANL (9.03 µg/L) (Windward 2020).



Source: National Water Quality Monitoring Council (2019)

Note: The vertical dashed line indicates the division between locations that are upstream of confluences draining from the Pajarito Plateau (left of line) and those that are downstream (right of line).

Figure 5-11. Dissolved copper concentrations in Rio Grande surface water



Note: The vertical dashed line indicates the division between locations that are upstream of confluences draining from the Pajarito Plateau (left of line) and those that are downstream (right of line). The red line is the threshold above which copper exceeds the associated criterion.

Figure 5-12. Copper WQC exceedance ratios for Rio Grande surface waters

As discussed in Section 2.2, the proposed copper SSWQC do not entail new activities, such as new discharges or sources of copper, that could potentially lead to an increase in copper loads to the Rio Grande. In addition, surface flows from the Pajarito Plateau rarely reach the Rio Grande due to limited flow durations and infiltration in the canyon reaches upgradient of the Rio Grande (Section 3.3). Based on these considerations, adoption of the SSWQC is expected to remain protective of aquatic life uses in the Rio Grande.

6 Conclusions and Recommended Copper SSWQC

Over the past 40 years, the scientific understanding of metal toxicity and bioavailability to aquatic organisms and the corresponding environmental regulations have increased. EPA has revised nationally recommended copper WQC from a simple linear equation based on hardness to a mechanistic model (the copper BLM) that more accurately accounts for the modifying effect of site-specific water chemistry. Accordingly, BLM inputs and outputs were used to develop MLR equations proposed as copper SSWQC for surface waters of the Pajarito Plateau.

Streams on the Pajarito Plateau are thoroughly monitored under a variety of EPA and NMED programs, so it is a suitable setting for developing BLM-based WQC. Using a site-specific dataset generated from long-term monitoring, the current evaluation demonstrates that pH, DOC, and hardness concentrations account for 98% of the variation in BLM WQC. Therefore, the copper BLM can be estimated using a three-parameter MLR equation without losing significant accuracy, and while retaining the scientific rigor afforded by the BLM.

Given the high degree of agreement between the acute and chronic MLRs and the BLM, the equations presented in Section 6.1 can be adopted as copper SSWQC. They will provide accurate criteria that are protective of aquatic life in surface waters of the Pajarito Plateau, consistent with EPA recommendations and New Mexico WQS (20.6.4.10 NMAC).

6.1 Proposed Copper SSWQC Equations and Applicability

MLR equations were developed for both acute and chronic copper SSWQC for application to surface waters of the Pajarito Plateau. The use of one or both of the SSWQC depends on the hydrologic classification of the waterbody, as described below.

The proposed acute SSWQC is as follows:

$$\boldsymbol{SSWQC_{acute}} = \boldsymbol{exp}(\mathbf{-22.914} + \mathbf{1.017} \times \boldsymbol{ln}(\boldsymbol{DOC}) + \mathbf{0.045} \times \boldsymbol{ln}(\boldsymbol{hardness}) + \mathbf{5.176} \times \boldsymbol{pH} - \mathbf{0.261} \times \boldsymbol{pH^2})$$

The proposed chronic SSWQC is as follows:

$$\boldsymbol{SSWQC_{chronic}} = \boldsymbol{exp}(\mathbf{-23.391} + \mathbf{1.017} \times \boldsymbol{ln}(\boldsymbol{DOC}) + \mathbf{0.045} \times \boldsymbol{ln}(\boldsymbol{hardness}) + \mathbf{5.176} \times \boldsymbol{pH} - \mathbf{0.261} \times \boldsymbol{pH^2})$$

As described in Section 3.3, the Pajarito Plateau has ephemeral, intermittent, and perennial surface waters. Hydrologic classifications did not influence the ability of the proposed acute and chronic SSWQC to accurately estimate BLM-based WQC. Therefore, the acute and chronic copper SSWQC equations can be applied to any water body on the Pajarito Plateau.

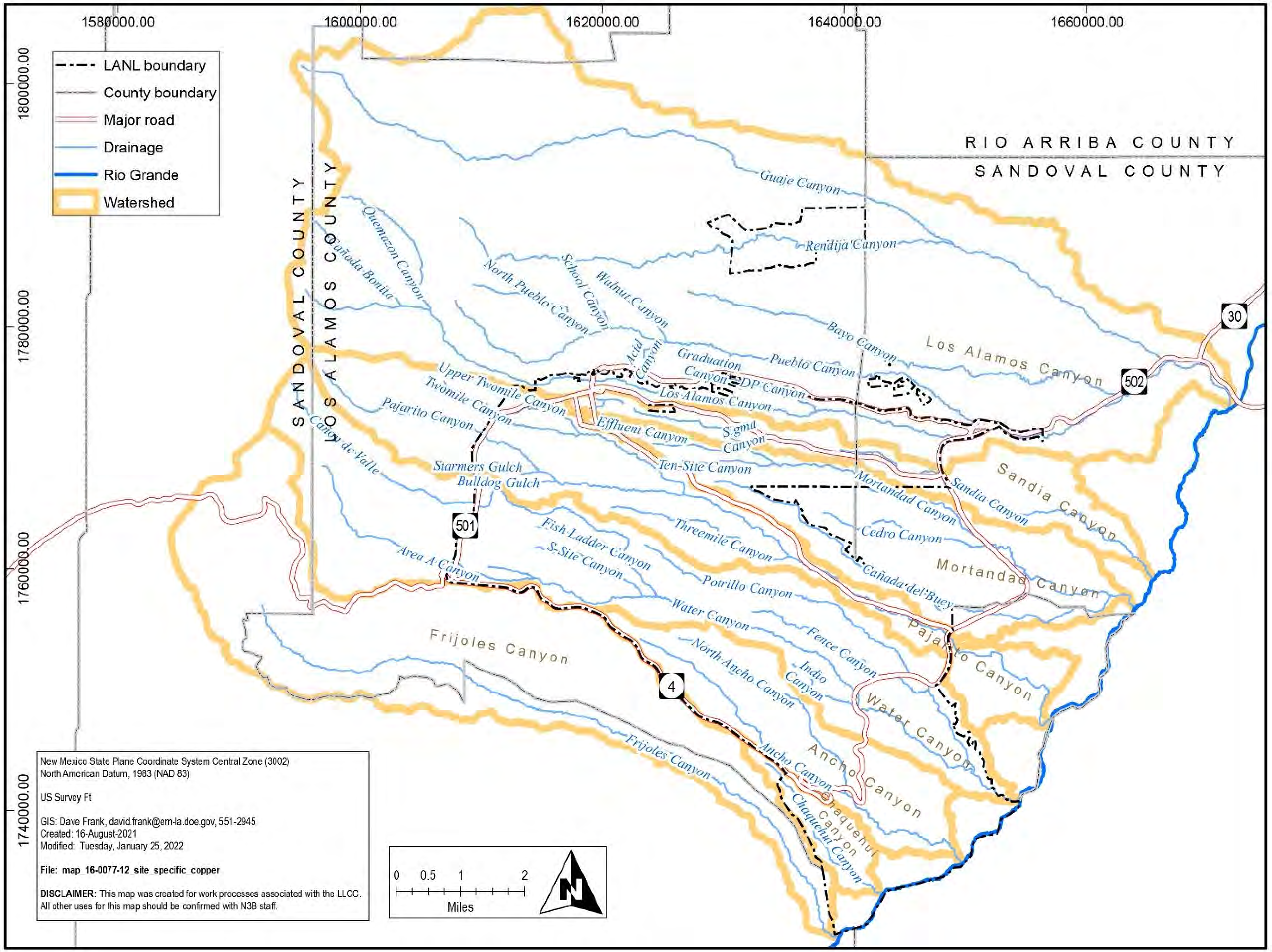
Most water bodies within the Laboratory's vicinity are classified as ephemeral or intermittent (20.6.4.128 NMAC); they are therefore designated as providing a limited aquatic life use and are subject to acute WQC only. Thus, the acute SSWQC equation would apply to those waters.

Other water bodies in the area are classified as perennial (20.6.4.126 and 20.6.4.121 NMAC) and are designated as providing higher-level aquatic life uses; these water bodies are subject to both acute and chronic aquatic life WQC. Unclassified surface water segments (20.6.4.98 NMAC) are designated as providing a marginal warm water aquatic life use and are subject to both acute and chronic WQC. Both the acute and chronic equations would apply to perennial and unclassified waters of the Pajarito Plateau.

As discussed in Section 2.4, the copper SSWQC are intended for eventual use in NPDES permits applicable to surface waters of the Pajarito Plateau. If the proposed copper SSWQC are adopted into New Mexico's WQS, updated TALs, benchmarks, and water quality-based effluent limits would be developed in accordance with each permitting program using the SSWQC criteria equations and appropriate datasets.

6.2 Spatial Boundaries for Proposed SSWQC

The spatial boundaries for the proposed SSWQC include all watersheds within the area of the Pajarito Plateau, from the Guaje Canyon watershed in the north to El Rito de Frijoles watershed in the south, from their headwaters to their confluence with the Rio Grande (Map 6-1). This area includes tributary streams and ephemeral or intermittent waters, regardless of whether they have a direct confluence with the Rio Grande or sufficient flow to reach the Rio Grande under normal conditions. Table 6-1 presents all AUs included in this area, their current classifications under NMAC, and their associated designated uses. The applicability of the acute and chronic SSWQC are also provided.



Map 6-1. Spatial boundary for proposed copper SSWQC

Table 6-1. Pajarito Plateau AUs Where SSWQC Would Apply

					Designated Use[a]							
AU ID	Major Watershed	AU Name	Stream Type	NMAC Class	SSWQC Applicability	AL	Irr.	LW	WH	DW	PC	SC
NM-9000.A_054	Ancho	Ancho Canyon (Rio Grande to North Fork Ancho)	ephemeral	128	acute only	X		X	X			X
NM-9000.A_055	Ancho	North Fork Ancho Canyon (Ancho Canyon to headwaters)	ephemeral	128	acute only	X		X	X			X
NM-9000.A_046	Chaquehui	Ancho Canyon (North Fork to headwaters)	ephemeral	128	acute only	X		X	X			X
NM-128.A_03	Chaquehui	Chaquehui Canyon (within LANL)	ephemeral	128	acute only	X		X	X			X
NM-9000.A_005	Chupaderos	Guaje Canyon (San Ildefonso bnd to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-2118.A_70	Frijoles	Rito de los Frijoles (Rio Grande to headwaters)	perennial	121	acute and chronic	X	X	X	X	X	X	
NM-126.A_03	Frijoles	Water Canyon (Area-A Canyon to NM 501)	perennial	126	acute and chronic	X	X	X	X			X
NM-97.A_002	Los Alamos/Pueblo	Acid Canyon (Pueblo Canyon to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-97.A_007	Los Alamos/Pueblo	Bayo Canyon (San Ildefonso bnd to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-128.A_14	Los Alamos/Pueblo	DP Canyon (Grade control to upper LANL bnd)	ephemeral	128	acute only	X		X	X			X
NM-128.A_10	Los Alamos/Pueblo	DP Canyon (Los Alamos Canyon to grade control)	intermittent	128	acute only	X		X	X			X
NM-97.A_005	Los Alamos/Pueblo	Graduation Canyon (Pueblo Canyon to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-97.A_003	Los Alamos/Pueblo	Kwage Canyon (Pueblo Canyon to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-9000.A_063	Los Alamos/Pueblo	Los Alamos Canyon (DP Canyon to upper LANL bnd)	ephemeral	128	acute only	X		X	X			X
NM-127.A_00	Los Alamos/Pueblo	Los Alamos Canyon (Los Alamos Rsvr to headwaters)	perennial	127	acute and chronic	X	X	X	X		X	
NM-9000.A_006	Los Alamos/Pueblo	Los Alamos Canyon (NM-4 to DP Canyon)	ephemeral	128	acute only	X		X	X			X
NM-9000.A_000	Los Alamos/Pueblo	Los Alamos Canyon (San Ildefonso bnd to NM-4)	intermittent	98	acute and chronic	X		X	X		X	
NM-9000.A_049	Los Alamos/Pueblo	Los Alamos Canyon (upper LANL bnd to Los Alamos Rsvr)	ephemeral	98	acute and chronic	X		X	X		X	

AU ID	Major Watershed	AU Name	Stream Type	NMAC Class	Designated Use[a]							
					SSWQC Applicability	AL	Irr.	LW	WH	DW	PC	SC
NM-9000.A_043	Los Alamos/Pueblo	Pueblo Canyon (Acid Canyon to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-99.A_001	Los Alamos/Pueblo	Pueblo Canyon (Los Alamos Canyon to Los Alamos WWTP)	ephemeral	98	acute and chronic	X		X	X		X	
NM-97.A_006	Los Alamos/Pueblo	Pueblo Canyon (Los Alamos WWTP to Acid Canyon)	ephemeral	98	acute and chronic	X		X	X		X	
NM-9000.A_045	Los Alamos/Pueblo	Rendija Canyon (Guaje Canyon to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-97.A_029	Los Alamos/Pueblo	South Fork Acid Canyon (Acid Canyon to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-97.A_004	Los Alamos/Pueblo	Walnut Canyon (Pueblo Canyon to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-128.A_00	Mortandad	Canada del Buey (within LANL)	ephemeral	128	acute only	X		X	X			X
NM-128.A_17	Mortandad	Ten Site Canyon (Mortandad Canyon to headwaters)	ephemeral	128	acute only	X		X	X			X
NM-128.A_16	Pajarito	Arroyo de la Delfe (Pajarito Canyon to headwaters)	ephemeral	128	acute only	X		X	X			X
NM-126.A_01	Pajarito	Pajarito Canyon (Arroyo de La Delfe to Starmers Spring)	perennial	126	acute and chronic	X	X	X	X			X
NM-128.A_08	Pajarito	Pajarito Canyon (lower LANL bnd to Two Mile Canyon)	ephemeral	128	acute only	X		X	X			X
NM-9000.A_040	Pajarito	Pajarito Canyon (Rio Grande to LANL bnd)	ephemeral	98	acute and chronic	X		X	X		X	
NM-128.A_06	Pajarito	Pajarito Canyon (Two Mile Canyon to Arroyo de La Delfe)	intermittent	128	acute only	X		X	X			X
NM-9000.A_048	Pajarito	Pajarito Canyon (upper LANL bnd to headwaters)	intermittent	98	acute and chronic	X		X	X		X	
NM-128.A_07	Pajarito	Pajarito Canyon (within LANL above Starmers Gulch)	intermittent	128	acute only	X		X	X			X
NM-9000.A_091	Pajarito	Three Mile Canyon (Pajarito Canyon to headwaters)	ephemeral	128	acute only	X		X	X			X
NM-128.A_15	Pajarito	Two Mile Canyon (Pajarito to headwaters)	ephemeral	128	acute only	X		X	X			X
NM-9000.A_053	Rio Grande	Canada del Buey (San Ildefonso Pueblo to LANL bnd)	ephemeral	98	acute and chronic	X		X	X		X	
NM-9000.A_042	Sandia	Mortandad Canyon (within LANL)	ephemeral	128	acute only	X		X	X			X

AU ID	Major Watershed	AU Name	Stream Type	NMAC Class	Designated Use[a]							
					SSWQC Applicability	AL	Irr.	LW	WH	DW	PC	SC
NM-9000.A_047	Sandia	Sandia Canyon (Sigma Canyon to NPDES outfall 001)	perennial	126	acute and chronic	X	X	X	X			X
NM-128.A_11	Sandia	Sandia Canyon (within LANL below Sigma Canyon)	ephemeral	128	acute only	X		X	X			X
NM-128.A_01	Water/Cañon de Valle	Canon de Valle (below LANL gage E256)	ephemeral	128	acute only	X		X	X			X
NM-126.A_00	Water/Cañon de Valle	Canon de Valle (LANL gage E256 to Burning Ground Spr)	perennial	126	acute and chronic	X	X	X	X			X
NM-9000.A_051	Water/Cañon de Valle	Canon de Valle (upper LANL bnd to headwaters)	intermittent	98	acute and chronic	X		X	X		X	
NM-128.A_02	Water/Cañon de Valle	Canon de Valle (within LANL above Burning Ground Spr)	ephemeral	128	acute only	X		X	X			X
NM-128.A_04	Water/Cañon de Valle	Fence Canyon (above Potrillo Canyon)	ephemeral	128	acute only	X		X	X			X
NM-128.A_05	Water/Cañon de Valle	Indio Canyon (above Water Canyon)	ephemeral	128	acute only	X		X	X			X
NM-128.A_09	Water/Cañon de Valle	Potrillo Canyon (above Water Canyon)	ephemeral	128	acute only	X		X	X			X
NM-9000.A_044	Water/Cañon de Valle	Water Canyon (Rio Grande to lower LANL bnd)	ephemeral	98	acute and chronic	X		X	X		X	
NM-9000.A_052	Water/Cañon de Valle	Water Canyon (upper LANL bnd to headwaters)	intermittent	98	acute and chronic	X		X	X		X	
NM-128.A_12	Water/Cañon de Valle	Water Canyon (within LANL above NM 501)	intermittent	128	acute only	X		X	X			X
NM-128.A_13	Water/Cañon de Valle	Water Canyon (within LANL below Area-A Cyn)	ephemeral	128	acute only	X		X	X			X

[a] AL – aquatic life; Irr. – irrigation; LW – livestock watering; WH – wildlife habitat; DW – drinking water; PC – primary contact; SC – secondary contact

AU – assessment unit

ID – identification

NMAC – New Mexico Administrative Code

SSWQC – site-specific water quality criteria

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Appendix A

BLM Dataset for Pajarito Plateau Surface Waters
(on CD included with this document)

APPENDIX B. SUPPLEMENTAL STATISTICAL ANALYSES

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Acronyms

AIC	Akaike's Information Criterion
BIC	Bayesian Information Criterion
BLM	biotic ligand model
DOC	dissolved organic carbon
DQA	data quality assessment
DQO	data quality objective
EIM	Environmental Information Management
EPA	US Environmental Protection Agency
LANL	Los Alamos National Laboratory
MLR	multiple linear regression
N3B	Newport News Nuclear BWXT-Los Alamos, LLC
NMAC	New Mexico Administrative Code
RCRA	Resource Conservation and Recovery Act
SSWQC	site-specific water quality criteria
TOC	total organic carbon
Windward	Windward Environmental LLC
WQS	water quality standards
WM	snowmelt (water sample type)
WP	persistent flow (water sample type)
WS	surface water (water sample type)
WT	storm water (water sample type)

B1 Overview

This appendix provides additional information on the development of copper site-specific water quality criteria (SSWQC) proposed for surface waters on the Pajarito Plateau, Los Alamos County, New Mexico. The general approach is discussed in the main text, but this appendix provides additional technical details. The approach involves developing multiple linear regressions (MLRs) that accurately predict US Environmental Protection Agency (EPA) (2007) copper biotic ligand model (BLM) criteria based on available site-specific water chemistry.

The remainder of this appendix is organized as follows:

- Section B2 – Data Aggregation
- Section B3 – Data Analysis Methods
- Section B4 – Model Evaluation
- Section B5 – Model Uncertainty
- Section B6 – Summary of MLR Development
- Section B7 – References

Section B2 provides a discussion of the aggregation of the Los Alamos National Laboratory's (LANL's) BLM data that were used to develop and evaluate MLRs. Section B3 provides a detailed discussion of the methods used to develop MLRs, and Section B4 presents the results of the development process. Section B5 provides a brief evaluation of dataset and model uncertainties not discussed in Sections B3 or B4, including a detailed evaluation of models using updated hydrology classifications based on recent hydrology protocol assessments by the New Mexico Environment Department (NMED) and Triad National Security. Section B6 summarizes the key results and conclusions from the development of MLRs. References cited in this appendix are presented in Section B7.

B2 Data Aggregation

This section describes the aggregation of BLM data for the development of MLRs. Aggregation involved the acquisition of source data, estimation of missing data to fill gaps, and cleanup and removal of data. Cleanup and removal of data occurred at different points during the aggregation process, as certain limitations of the dataset (with respect to BLM calculations and MLR development) were recognized.

B2.1 SOURCE DATA

The source dataset was generated by LANL/Newport News Nuclear BWXT-Los Alamos, LLC (N3B) and their contractors, uploaded to the Environmental Information Management (EIM) database, and then exported and provided to Windward Environmental LLC (Windward) by N3B. This occurred in two phases for data included in the 2018 data quality objective (DQO)/data quality assessment (DQA) report (Windward 2018) and for data collected through 2019. All data were reviewed and treated in a similar manner. The complete dataset (2005 to 2019) was compiled to provide all available EIM records for the following information:

- BLM analyte concentrations, starting with pH and dissolved organic carbon (DOC) pairs but including all parameters as available
- Secondary analytes that could aid in filling data gaps and further interpretation of the BLM dataset and outcomes (e.g., hardness and specific conductance)
- Water sample types, including surface water (WS), snowmelt (WM), persistent flow (WP), and storm water (WT)[1]
- Sampling location names, aliases, and coordinates
- Analytical quality control/validation flags
- Other sample information deemed to be of potential interest by N3B (e.g., sampling method and date, analytical method, sample preparation/filtration method, sampling program)

N3B also provided various other sample classifications not currently in EIM that could support SSWQC development. These classifications were generally produced through GIS analysis and field surveys conducted at the LANL property (hereinafter referred to as the Laboratory). These classifications included but were not limited to New Mexico Administrative Code (NMAC) stream hydrologic type, additional sample type classification (e.g., "stormwater runoff" versus "surface water"), land use, and historical wildfires. "Stormwater runoff" data were excluded from the development of the MLR, because the BLM is intended to apply to receiving water streams (including stormflow events), not to stormwater discharge or effluent.

[1] A subset of stormwater samples was excluded from the BLM dataset because these samples were not clearly associated with a surface water assessment unit. These samples were collected at or near a stormwater discharge point rather than in a stream channel during a stormflow event.

B2.2 Aggregation and Addressing Data Gaps

Starting with the source dataset (n = 1,323 events), acceptable data were sequentially selected for use. Aggregation steps for BLM parameters (including steps wherein BLM parameters were estimated) were as follows:

1) Process used measured concentrations of each parameter from filtered samples for each event, if available.
2) When measured, filtered concentrations were not available for pH and alkalinity, so unfiltered sample results from the same event were used. Unfiltered alkalinity was shown by Windward (2018) to be comparable to filtered alkalinity in paired samples. The measurement of pH is almost always measured in unfiltered samples.
3) To fill gaps in the dataset, DOC was estimated from total organic carbon (TOC) for a subset of samples by applying a conversion factor, discussed later in this section.
4) If measured concentrations were unavailable from both filtered and unfiltered samples, some BLM input parameters were estimated from another water chemistry characteristic; for example, hardness was calculated from calcium and magnesium.[2]
5) For samples with BLM inputs that could not be estimated reasonably from another water chemistry characteristic (i.e., measured in neither filtered nor unfiltered samples), an average concentration was used for the location (using concentrations from other samples from the same location). This approach applied only to sulfate and chloride.
6) If no data were available for a BLM input, then either a default value from the BLM guidance was applied (e.g., 10% humic acid), or a sensitivity analysis was performed to identify a static input value leading to a conservative BLM output. The sensitivity analysis step applied to temperature only and had been carried out previously by Windward (2018).

Non-detected analytical results were replaced by one-half the detection limit. This approach was used because statistical approaches (e.g., Kaplan-Meier method, maximum likelihood estimation, or regression on order statistics) are not appropriate for predicting single concentrations.[3]

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[2] A standard equation for calculating total hardness in mg/L calcium carbonate was used: hardness = 2.5 × calcium + 4.1 × magnesium.

[3] Rather, non-detect estimation methods such as the Kaplan-Meier method are appropriate for estimating summary statistic parameters like the mean and confidence limits.

Consistent with the 2018 DQO/DQA evaluation, a conservative temperature of 10°C was applied to all samples when running the BLM (Windward 2018). This is the lower bound of the BLM's prescribed range for temperature (Windward 2019), and temperature is known to have little if any effect on BLM output. Humic acid was set to 10% for all samples, consistent with guidance (Windward 2019). Sulfide was set equal to the lower bound of the BLM's prescribed range, 1×10^{-3} mg/L (Windward 2019).

As described by EPA (2007), the proportion of organic carbon expected to be dissolved can be estimated based on relationships between paired measures of DOC and TOC. Because the estimation of DOC from TOC was necessary for 124 samples in which only TOC was measured, a comparison of paired measures of DOC and TOC for surface water samples from the Pajarito Plateau was performed. Various approaches were used to compare DOC and TOC, including regression and ratio-based approaches (carried out using R software) (R Core Team 2020). Linear, log-linear, and quantile (median) regression methods were applied to the DOC and TOC data, and outliers were identified and removed based on large model residuals (i.e., prediction error) or influence (quantified using Cook's distance metric and screened against a metric threshold of 0.5). Additionally, mean and median DOC-to-TOC ratios were calculated as a relatively simple approach, consistent with EPA (2007) recommendations. EPA (2007) also provides default nationwide and state-specific conversion factors; these were used as a basis for comparison and confirmation of the calculated, site-specific conversion factor.

Regardless of the method used, there were concerns with the underlying DOC and TOC data for the specific purpose of predicting DOC from TOC,[4] because the mean and median DOC-to-TOC ratios exceeded one; more than one-half of the available DOC data exceeded TOC in paired samples. While it is theoretically not possible for DOC to exceed TOC, the data seeming to contradict this theory came from the standard sampling and analytical protocols used at LANL for DOC and TOC. Specifically, LANL measures organic carbon in filtered (DOC) and unfiltered (TOC) samples, which come from separate aliquots of a sample and possibly from separate sample bottles filled during the same event. This approach allows for variability and uncertainty inherent to the analytical instrument, sampling method, sample preparation (e.g., filtration), etc., all of which can result in DOC appearing to exceed TOC. To address this uncertainty in a conservative way, samples were considered only when DOC was less than or equal to TOC.5

[4] The data used for this purpose were collected and analyzed using standard methods, and the resulting concentrations were validated by an independent party; therefore, the data are considered to be of high quality in general and so were not discarded from the dataset.

[5] This limitation on the dataset only applied to the calculation of a DOC-to-TOC conversion faction, not to the entire MLR development process.

The median DOC-to-TOC ratio of 0.859 was used as the final conversion factor. This value is virtually identical to the conversion factor used by Windward (2018) (0.86) and the national average presented by EPA (2007) (0.857) for streams; it is also similar to the value (0.83) used by the Oregon Department of Environmental Quality in its copper BLM-based WQC implementation guidance (Oregon DEQ 2016), as well as the New Mexico state-specific factor from EPA (2007) (0.815). The median ratio was also comparable to the model slopes from the linear, log-linear, and quantile regression approaches (after removing outliers but not excluding values wherein DOC exceeded TOC). Therefore, it provides reasonable and defensible estimates of DOC in Pajarito Plateau waters for the subset of samples in which DOC was estimated from TOC. Section B5.2.4 provides additional discussion of the influence of DOC on MLR development.

After working through the above steps, the following numbers of samples were sequentially aggregated:

- Among the 1,323 initial location-date sample pairings in the BLM dataset, there were 10 instances in which pH, DOC, and alkalinity were all measured in filtered samples. These samples were retained.
- A total of 479 samples were retained after adding 469 samples with pH and alkalinity from unfiltered samples.[6]
- A total of 606 samples were retained after adding 127 samples with representations or estimates of DOC.
    - Three filtered samples in which TOC was reported and therefore assumed to be DOC (incorrectly reported in EIM)
    - 124 samples for which DOC was estimated from TOC
- A total of 611 events were retained after inputting major anion data for 5 events.
    - Four samples lacked sulfate concentrations, so they were estimated using location-specific averages.
    - One sample lacked a chloride concentration, so it was estimated using a location-specific average.

B2.3 Data Cleanup

At the conclusion of the data aggregation steps described in Section B2.2, 611 samples had been retained. Data reduction steps were then taken to limit the dataset to BLM-relevant samples. First, any duplicated sample entries in EIM (of which four were observed) were reduced to a single unique sample. Then, all "stormwater discharge"

[6] Alkalinity from unfiltered samples was used as a substitute for missing dissolved alkalinity inputs. This was consistent with the 2018 DQO approach, which determined that unfiltered and filtered alkalinity values were comparable (when both values were reported for a single sample).

samples were excluded, leaving only surface water samples (including many "WT" stormflow samples). Lastly, any samples with pH, DOC, or hardness values falling outside the BLM's prescribed ranges (Table 5-2 of the main text) were excluded. After data cleanup, the result was a modeling dataset with 517 samples.

B2.4 Final Dataset

Table B1 shows a tabular breakdown of the 517 samples used for MLR development by major watershed and current NMAC hydrologic classification.[7]

Table B1. New Mexico WQS hydrologic classification assignments for the BLM dataset by major watershed

Major Watershed	NMAC Hydrological Classification			N by Watershed
	Ephemeral/ Intermittent (128)	Default Intermittent (98)	Perennial (121/126)	
Ancho	4	0	0	4
Chaquehui	3	0	0	3
Frijoles	0	9	8	17
Jemez River	0	6	0	6
Los Alamos/Pueblo	140	61	0	201
Mortandad	28	2	0	30
Pajarito	62	0	3	65
Sandia	8	0	148	156
Water/Cañon de Valle	4	12	19	35
N by Hydrology Class	**249**	**90**	**178**	**517**

BLM – biotic ligand model
N – sample size
NMAC – New Mexico Administrative Code
WQS – water quality standards

Appendix A provides the final dataset of BLM data, including the 517 samples used to develop MLRs and the 14 samples removed during the final data filtering step. The exclusion of data outside the prescribed BLM range (for pH, DOC, and hardness) was intended to avoid extrapolation of the BLM; however, BLM guidance suggests that removing such data is not necessary (Windward 2019). Therefore, the 14 samples removed during the last filtering step are included in Appendix A to facilitate future modeling efforts, which may include BLM data outside the prescribed ranges. Thus, the dataset provided in Appendix A includes 531 samples with all data needed to run the copper BLM.

[7] Figure 3-1 and Map 3-1 in the main text provide additional spatial context for the BLM dataset.

B2.5 ADDITIONAL DATA CONSIDERATIONS

Although land use can have an effect on downgradient water quality, there is no need to separate these data when developing or evaluating an MLR, if it can be demonstrated the MLR equation responds as well as the BLM software does to changes in water quality. This is discussed further in Section B5.2. Evaluations of samples potentially affected by historical fires showed BLM WQC and MLR-predicted WQC similar to those of unaffected samples; this is discussed in Section B5.3. Therefore, data potentially affected by different land uses and/or historical fires were not treated differently from other data when developing MLRs.

Hydrology was investigated in detail when developing the MLR (Sections B3 and B4), because of the various water types on the Pajarito Plateau (i.e., ephemeral, intermittent, and perennial). According to New Mexico water quality standards (WQSs), stream hydrology determines whether acute only or both acute and chronic WQC apply, so the proposed acute and chronic SSWQC, if adopted, would apply similarly.[8] For the purposes of developing and testing MLRs, existing NMAC hydrologic classifications for LANL waters were used (Section B4); however, Section B5.4 also details the investigation of proposed classifications from the most recent hydrology protocol efforts by NMED and the Laboratory. These updated classifications have not yet been approved, but they represent reasonable changes to previously unclassified (20.6.4.98 NMAC) waters based on standard methods.

B3 Data Analysis Methods

The final BLM dataset was evaluated iteratively to select the final MLR equation that accurately and most precisely predicted the BLM WQC. To arrive at a parsimonious model, the process considered the effects of continuous water quality variables, hydrological classification, and the possible influences of other sampling location characteristics not included in the model. Analyses were conducted using a series of well-accepted statistical methods (including common graphical evaluations), all of which were carried out in the R statistical environment (R Core Team 2020).

B3.1 INITIAL MODEL

An initial log-log linear MLR was developed and tested that included the parameters pH, DOC, and hardness. DOC and hardness were transformed using the natural log, whereas pH, already reported as a log-unit, was input to the model as-is. The structure of the initial model (Model 1) formed the basis for comparisons of models described in Section B3.2.

[8] Acute WQC apply in ephemeral and intermittent streams, whereas acute and chronic WQC apply in perennial and unclassified streams.

$$\ln(BLM) = intercept + \ln(DOC) + \ln(hardness) + pH$$ **Model 1**

Where:

BLM = calculated BLM-based WQC

ln = the natural logarithm

B3.2 Hydrologic Classification-specific Models

To address potential differences in model performance (or bias) among NMAC hydrologic classifications, these classifications were added to MLRs in different ways and tested over several rounds. The first round of analyses evaluated the precision and goodness of fit of a "full" model (Model 2)[9] that included the main categorical and continuous variables assumed to be important for predicting the BLM WQC. Three continuous water quality variables—DOC, hardness, and pH—were selected *a priori* to incorporate primary mechanisms that underpin the copper BLM (EPA 2007; Brix et al. 2017). Model 2 also included NMAC hydrological classifications (i.e., ephemeral/intermittent, intermittent, or perennial) as a categorical term, which introduced classification-specific slopes (for each of the continuous variables) and intercepts.

$$\ln(BLM) = HC_{int} + HC_{slope\_DOC} * \ln(DOC) + HC_{slope\_hardness} * \ln(hardness) + HC_{slope\_pH} * pH$$

Model 2

Where:

HC_{int} = hydrologic classification-specific intercept

HC_{slope} = hydrologic classification-specific and continuous variable-specific slope

Stepwise regression procedures based on the Akaike's and Bayesian Information Criteria (AIC and BIC) were used to determine whether the hydrology-specific slopes and/or intercepts provided statistically important contributions to the prediction of BLM WQC.[10] In other words, it was determined whether or not slopes and/or intercepts for DOC, hardness, and pH differed statistically among hydrologic classifications and how important those slopes and intercepts were for predicting the BLM WQC. When running the stepwise regression algorithm, the computational output describes the best-fitting equation, which contains only those parameters that

[9] In this appendix, the terms "Model" and "Equation" are used in different ways. They are distinguished as the general structure of the equation (model) versus the equation with specified coefficient values (equation).

[10] To control model complexity, the AIC and BIC reduce (penalize) the measure of model fit based on the number of parameters in the model. The BIC also penalizes the fit based on sample size. Above a certain sample size, AIC tends to result in larger models (i.e., retain more model terms), whereas BIC tends to generate smaller models with fewer terms.

significantly improve BLM WQC predictions. The final list of AIC or BIC model parameters is always a subset of the full model, potentially including all of the parameters in the full model.

The full model (including all hydrologic class-specific slopes and intercepts) was compared to the best-fitting models generated by each stepwise procedure using a number of statistics and visual tools. These tools described each model's goodness-of-fit (of predicted WQC to calculated WQC values) and the extent to which model residuals[11] met the assumptions of the linear modeling framework. The summary statistics reported include:

- Adjusted R^2 – fraction of variance in the BLM WQC explained by the MLR, penalized for the number of variables in the model
- Predicted R^2 – ability of MLR to predict out-of-sample BLM WQC and therefore a measure of how well the model might predict future WQC; also describes model's reliance on single data points, with low predicted R^2 suggesting that model has too many parameters
- AIC and BIC – measures of model fit, with lower values indicating better fit
- Shapiro-Wilk test – indicates whether residuals are normally distributed (assumption of MLR), with $p < 0.05$ suggesting non-normality
- Scores test – indicates whether residuals are homoscedastic (assumption of MLR), with $p < 0.05$ suggesting non-constant variance or heteroscedasticity

Standard diagnostic plotting methods of model residuals were evaluated, including plots to assess normality, homogeneity of variance, and relationships between residuals and independent continuous variables of the model (i.e., pH, DOC, and hardness).[12] Residual distributions were plotted by watershed and by hydrologic class to assess whether models were performing similarly across these categories.

In addition, the magnitudes of any statistically significant differences between hydrology-specific model terms were considered in terms of their impact on or relevance to ecological and regulatory issues. In other words, it was determined whether a significant difference was large enough to warrant an increase in MLR complexity. In addition to potentially impacting the predictive capability of the MLR for future data, increased complexity can make the model more difficult to use as a regulatory tool, for example, by requiring that the hydrological classification of a sampling location be known prior to applying the MLR.

[11] Model residuals = actual WQC – predicted WQC
[12] Default plots were generated in R using the plot.lm function.

Using the information about the importance of individual model terms provided by each line of investigation of model fit, the tradeoffs of simpler and more complex models were assessed, and a final set of models was recommended. The steps taken to refine the full model are described more completely in Section B4.

B4 Model Evaluations

This section provides the results of MLR development. Section B4.1 discusses the initial model (Model 1), and Section B4.2 discusses the hydrologic classification-specific models (Models 2 through 4) and the final model (Model 5).

B4.1 Initial Model Evaluation

Table B2 provides a summary of the initial model, Model 1. Evaluation of this model did not involve a stepwise regression step, since only the full model was considered. Subsequent models are discussed in Section B4.2. The model fit was strong even without added complexity (e.g., addition of hydrology classification factors), with an adjusted R^2 value of 0.969 and a predicted R^2 value of 0.968.

Table B2. Summary of MLR based on Model 1 structure

Model Parameter	Model Coefficient	Standard Error	Coefficient Significance (p-value)
Intercept	-8.21655	0.10778	<0.0001
DOC slope	1.00066	0.01039	<0.0001
Hardness slope	0.01166	0.01110	0.294
pH slope	1.27290	0.01625	<0.0001
Adjusted R^2	**0.969**		
Predicted R^2	**0.968**		

DOC – dissolved organic carbon

MLR – multiple linear regression

B4.2 Hydrologic Classification-specific Model Evaluation

The more complex Model 2 resulted in high adjusted and predicted R^2 values of 0.973 and 0.971, respectively (Table B3), although these values represented increases of only 0.004 and 0.003, respectively, relative to Model 1 (Table B2). The AIC and BIC models both resulted in the removal of hydrology-specific slopes for DOC and hardness but not pH.

Table B3. Summary of MLRs based on the Model 2 structure with comparison of full, AIC, and BIC models

Hydrologic Classification	Model Parameter	Model Coefficient		Coefficient Significance (p-value)[a]	
		Full	AIC/BIC Model	Full	AIC/BIC Model
Ephemeral/intermittent	intercept	-9.387119	-9.349237	<0.0001	<0.0001
Intermittent	intercept	-8.345361	-8.416672	0.000992	0.00178
Perennial	intercept	-7.324505	-7.340531	<0.0001	<0.0001
Ephemeral/intermittent	DOC slope	1.0182168	1.012158	<0.0001	<0.0001
Intermittent	DOC slope	1.0000358	na[b]	0.488	na[b]
Perennial	DOC slope	1.0211608	na[b]	0.899	na[b]
Ephemeral/intermittent	hardness slope	0.014166	0.032618	0.389	0.00231
Intermittent	hardness slope	0.050238	na[b]	0.206	na[b]
Perennial	hardness slope	0.039968	na[b]	0.297	na[b]
Ephemeral/intermittent	pH slope	1.425394	1.413439	<0.0001	<0.0001
Intermittent	pH slope	1.275228	1.289743	0.00133	0.00262
Perennial	pH slope	1.140642	1.148362	<0.0001	<0.0001
Adjusted R^2		**0.973**	**0.973**		
Predicted R^2		**0.971**	**0.971**		

[a] The significances of perennial and ephemeral coefficients represent differences from intermittent coefficients.

[b] AIC and BIC models excluded hydrology-specific coefficient; coefficient and p-value reported in table for ephemeral/intermittent applies to all samples.

AIC – Akaike's Information Criterion
BIC – Bayesian Information Criterion
DOC – dissolved organic carbon
MLR – multiple linear regression
na – not applicable

A clear curvilinear pattern emerged when comparing the residuals to pH (Figure 5-4 in the main text), suggesting a non-linear relationship between pH and the BLM WQC (when combined with hardness, DOC, and other parameters in an MLR). To address this, a new term was added in the model to eliminate the curvilinearity: When a squared pH term (pH^2) was added to the model formula (Model 3),[13] the adjusted R^2 increased from 0.973 to 0.984 (Table B4), and residuals became more normally distributed.

$$\ln(BLM) = HC_{int} + HC_{slope\_DOC} * \ln(DOC) + HC_{slope\_hardness} * \ln(hardness) + HC_{slope+pH} * pH + HC_{slope\_pH2} * pH^2$$

Model 3

[13] The implication of using a pH^2 term in the MLR is that, when DOC and hardness remain constant, the relationship between pH and the BLM WQC is parabolic (curved). In this case, pH exerts a smaller effect on the predicted WQC at the extremes of the pH range compared to the middle of the range.

Table B4. Summary of MLRs based on the Model 3 structure with comparison of full, AIC, and BIC models

Hydrologic Classification	Model Parameter	Model Coefficient		Coefficient Significance (p-value)[a]	
		Full and AIC	BIC	Full and AIC	BIC
Ephemeral/intermittent	intercept	-26.237	-26.728	<0.0001	<0.0001
Intermittent	intercept	-30.37868	-26.214669	0.187	<0.0001
Perennial	intercept	-25.882931	-26.742375	0.899	0.899
Ephemeral/intermittent	DOC slope	1.016194	1.032831	<0.0001	<0.0001
Intermittent	DOC slope	1.021582	na[b]	0.794	na[b]
Perennial	DOC slope	1.064993	na[b]	0.00849	na[b]
Ephemeral/intermittent	hardness slope	0.030987	0.052566	0.0180	<0.0001
Intermittent	hardness slope	0.080043	na[b]	0.0301	na[b]
Perennial	hardness slope	0.063531	na[b]	0.0967	na[b]
Ephemeral/intermittent	pH slope	6.089031	6.198747	<0.0001	<0.0001
Intermittent	pH slope	7.351267	na[b]	0.144	na[b]
Perennial	pH slope	5.959203	na[b]	0.865	na[b]
Ephemeral/intermittent	pH^2 slope	-0.323072	-0.330876	<0.0001	<0.0001
Intermittent	pH^2 slope	-0.420227	-0.33943	0.104	0.000152
Perennial	pH^2 slope	-0.314137	-0.328996	0.863	0.362
Adjusted R^2		**0.984**	**0.983**		
Predicted R^2		**0.981**	**0.981**		

[a] Significances of perennial and intermittent coefficients are differences from ephemeral/intermittent coefficients, whereas the significances of the ephemeral/intermittent coefficients are differences from zero.

[b] BIC model excluded hydrology-specific coefficient; coefficient and p-value reported in table for ephemeral/intermittent applies to all samples

AIC – Akaike's Information Criterion

BIC – Bayesian Information Criterion

DOC – dissolved organic carbon

MLR – multiple linear regression

na – not applicable

Although some hydrology-specific slopes and intercepts were retained by both the AIC and BIC stepwise procedures, the high adjusted R^2 and the relatively small differences among intercepts and slopes of the three hydrologic categories indicated that Model 3 could be simplified by removing the hydrology-specific slopes with little loss of information (Model 4). When hydrology-specific slopes were removed and a pH^2 term retained, Model 4 had both adjusted and predicted R^2 values of 0.981 (reduction of only 0.002 from Model 3), with little change in the patterns of residuals from the more complex model (Table B5).

$$\ln(BLM) = HC_{int} + \ln(DOC) + \ln(hardness) + pH + pH^2 \qquad \textbf{Model 4}$$

Table B5. Summary of MLR based on the Model 4 structure

Hydrological Classification	Model Parameter	Model Coefficient	Coefficient Significance (p-value)[a]
Ephemeral/intermittent	intercept	-24.793152	<0.0001
Intermittent	intercept	-24.731783	<0.0001
Perennial	intercept	-24.699674	<0.0001
na	DOC slope	1.028540	<0.0001
na	hardness slope	0.051764	<0.0001
na	pH slope	5.689560	<0.0001
na	pH^2 slope	-0.297282	<0.0001
Adjusted R^2		**0.982**	
Predicted R^2		**0.982**	

Note: AIC and BIC stepwise regression process resulted in the same equation as the full model.

[a] The significance of perennial and intermittent intercepts describe differences from the ephemeral/intermittent intercept, whereas the significance of the ephemeral/intermittent intercept is a difference from zero.

AIC – Akaike's Information Criterion
BIC – Bayesian Information Criterion
DOC – dissolved organic carbon
MLR – multiple linear regression
na – not applicable

As was true of the change between Models 2 and 3, the high adjusted R^2 and small differences among hydrology-specific intercepts indicated that an even simpler model than Model 4 could be adequate.

With a single intercept and single slopes for the continuous independent variables (Model 5), the adjusted and predicted R^2 values dropped to only 0.980 (from 0.981) (Table B6). Plots of calculated versus predicted BLM WQC values and MLR residuals versus independent variables (i.e., pH, DOC, and hardness) were similar to those from more complex models (Section B5).

$$\ln(\text{BLM}) = \text{intercept} + \ln(\text{DOC}) + \ln(\text{hardness}) + \text{pH} + \text{pH}^2 \qquad \textbf{Model 5}$$

Table B6. Summary of MLR based on the Model 5 structure

Model Parameter	Model Coefficient	Coefficient Significance (p-value)
Intercept	-23.0286	<0.0001
DOC slope	1.0131	<0.0001
Hardness slope	0.0466	<0.0001
pH slope	5.2063	<0.0001
pH^2 slope	-0.2627	<0.0001
Adjusted R^2	**0.980**	
Predicted R^2	**0.980**	

DOC – dissolved organic carbon
MLR – multiple linear regression

Based on the strong performance of and rationale for an MLR using the Model 5 structure, the final acute and chronic MLRs were generated using that structure (Tables B7 and B8).[14] These MLRs are proposed as the acute and chronic copper SSWQC. Table B9 provides a summary of the models described in this section.

Table B7. Final acute MLR

Model Parameter	Model Coefficient	Standard Error	Coefficient Significance (p-value)
Intercept	-22.914288	0.893512	<0.001
DOC slope	1.017377	0.008459	<0.001
Hardness slope	0.044941	0.009199	<0.001
pH slope	5.176081	0.236519	<0.001
pH^2 slope	-0.260743	0.015776	<0.001
Adjusted R^2	**0.980**		
Predicted R^2	**0.980**		

Note: Model structure based on Model 5 (Equation 1 in the main text).

DOC – dissolved organic carbon

MLR – multiple linear regression

Table B8. Final chronic MLR

Model Parameter	Model Coefficient	Standard Error	Coefficient Significance (p-value)
Intercept	-23.390522	0.893512	<0.001
DOC slope	1.017377	0.008459	<0.001
Hardness slope	0.044941	0.009199	<0.001
pH slope	5.176081	0.236519	<0.001
pH^2 slope	-0.260743	0.015776	<0.001
Adjusted R^2	**0.980**		
Predicted R^2	**0.980**		

Note: model structure based on Model 5 (Equation 2 in the main text).

DOC – dissolved organic carbon

MLR – multiple linear regression

[14] Because of the similarities between the acute and chronic BLMs (i.e., underlying toxicity datasets and chemical mechanisms), the MLR for predicting chronic BLM WQC was developed using the same methods as the acute MLR but using chronic BLM WQC instead of acute WQC as the dependent variable in the MLR.

Table B9. Summary statistics of MLR models fit to acute BLM WQC

Model Description	Development Method[a]	Adjusted R^2	Predicted R^2	AIC	BIC	Shapiro-Wilk Test p-value[b]	Scores Test p-value[c]
Model 1: Simplest model; includes pH, DOC, and hardness only (no distinction in hydrology)	full	0.969	0.968	-614	-593	<0.001	0.249
Model 2: Hydrology slopes and intercepts	full	0.973	0.971	-677	-621	<0.001	0.751
	AIC	0.973	0.971	-681	-643	<0.001	0.704
	BIC	0.973	0.971	-681	-643	<0.001	0.704
Model 3: Hydrology slopes and intercepts; pH^2 added	full	0.984	0.981	-928	-860	<0.001	0.0476
	AIC	0.984	0.981	-928	-860	<0.001	0.0476
	BIC	0.983	0.981	-918	-876	<0.001	0.00332
Model 4: Hydrology intercepts only (slopes excluded); pH^2 term always included	full	0.982	0.982	-899	-865	<0.001	0.0204
	AIC	0.982	0.982	-899	-865	<0.001	0.0204
	BIC	0.982	0.982	-899	-865	<0.001	0.0204
Model 5: No distinction in hydrology; pH^2 term always included; final models (proposed MLRs for copper SSWQC)	full (acute)	0.980	0.979	-833	-808	<0.001	0.083
	full (chronic)	0.980	0.979	-833	-808	<0.001	0.083

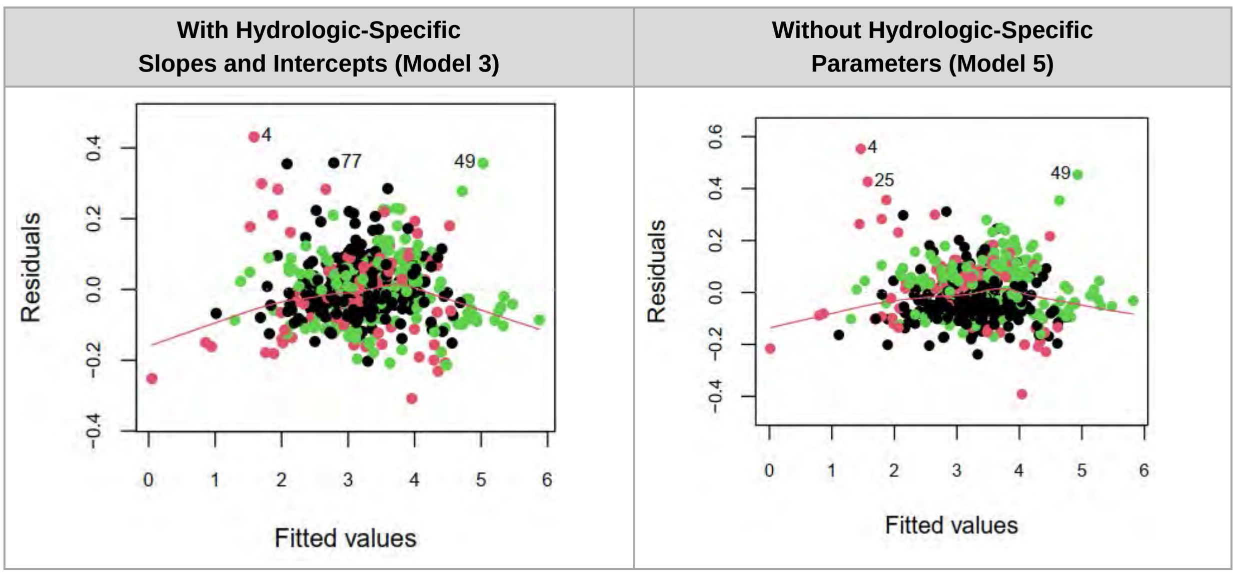
[a] Model descriptions are identified according to the key differences in model structure (left column) and the approach used to generate the model (right column). Key differences relate to the inclusion of hydrological classes as model parameters and the inclusion/exclusion of certain data. The approaches to generate the models include approaches for "full" models (i.e., all pre-determined variables included as indicated in the left column and including DOC, pH, and hardness) and AIC or BIC stepwise regression approaches, which involve sequentially adding and removing model parameters and checking improvements in model fit.

[b] Shapiro-Wilk test for normality of residuals; $p < 0.05$ indicates non-normality

[c] Score test for homogeneity of residuals; $p < 0.05$ indicates heteroscedasticity

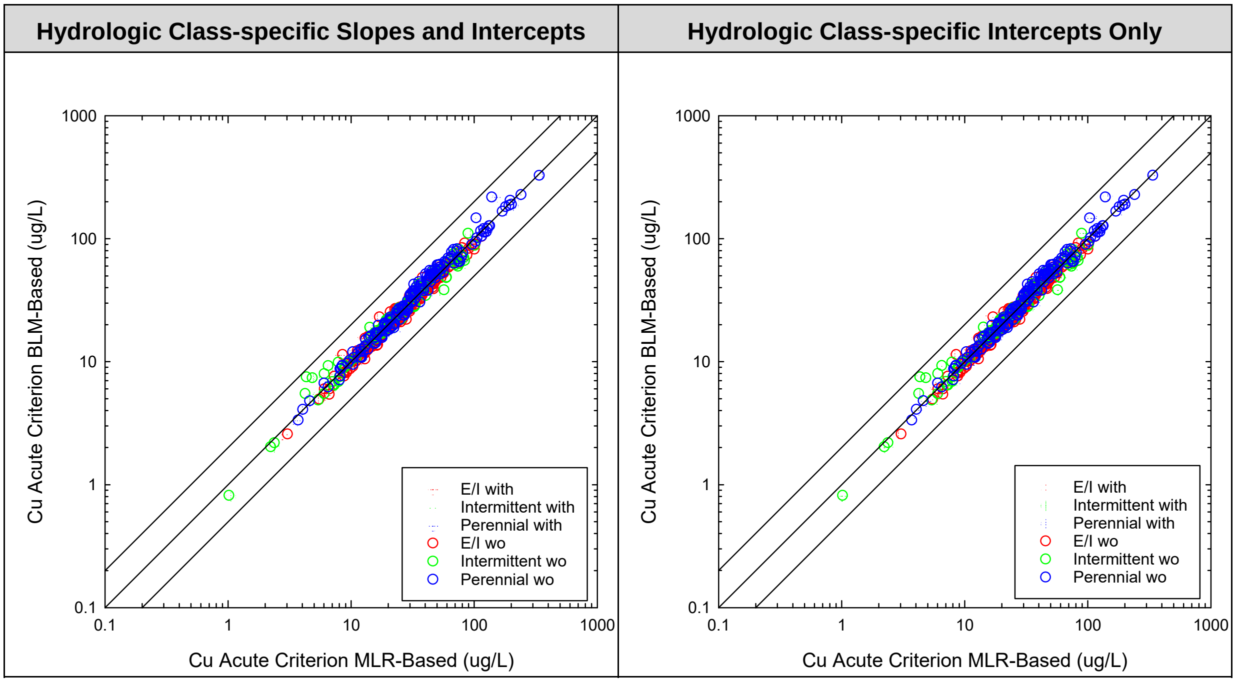
AIC - Akaike's Information Criterion
BIC – Bayesian Information Criterion
BLM – biotic ligand model
DOC – dissolved organic carbon
MLR – multiple linear regression
SSWQC – site-specific water quality criterion a
WQC – water quality criteriaon

Although the stepwise AIC and BIC models retained hydrology-specific intercepts and slopes when using Model 2 and 3 structures (Tables B3 and B4), hydrologic specificity did not eliminate residual patterns (Figure B1). Also, plots of calculated versus predicted BLM WQC values (Figure B2) show very small or negligible changes resulting from the inclusion or exclusion of hydrology-specific slopes. Moreover, the decrease in R^2 statistics (i.e., percent of variance in BLM WQC explained by the MLR) after removing hydrology-specific intercepts and/or slopes is small (< 1%) compared to the total variance explained (R^2 values, Tables B2 to B5). Together, these observations indicate that the hydrologic classification of a water body is not an important factor in site-specific MLRs relative to the continuous variables that underpin the BLM mechanisms.



Note: Point colors indicate hydrologic classification: black = ephemeral/intermittent, red = intermittent, and green = perennial. Red line is a curve fit to residuals indicating trend. Ideally, the curve would align with the dotted line.

Figure B1. Comparison of residual patterns for models with and without hydrologic classification-specific parameters



Note: Closed circles indicate the values predicted by the MLR with hydrologic-specific classification; open circles are predictions after removing hydrologic classification parameters from the MLR; dashed line is the 1:1 relationship between BLM and MLR output, and solid lines are plus or minus a factor of 2 from the 1:1 line.

Figure B2. Comparison of acute BLM-based WQC to MLR-based WQC with and without hydrologic-specific MLR terms

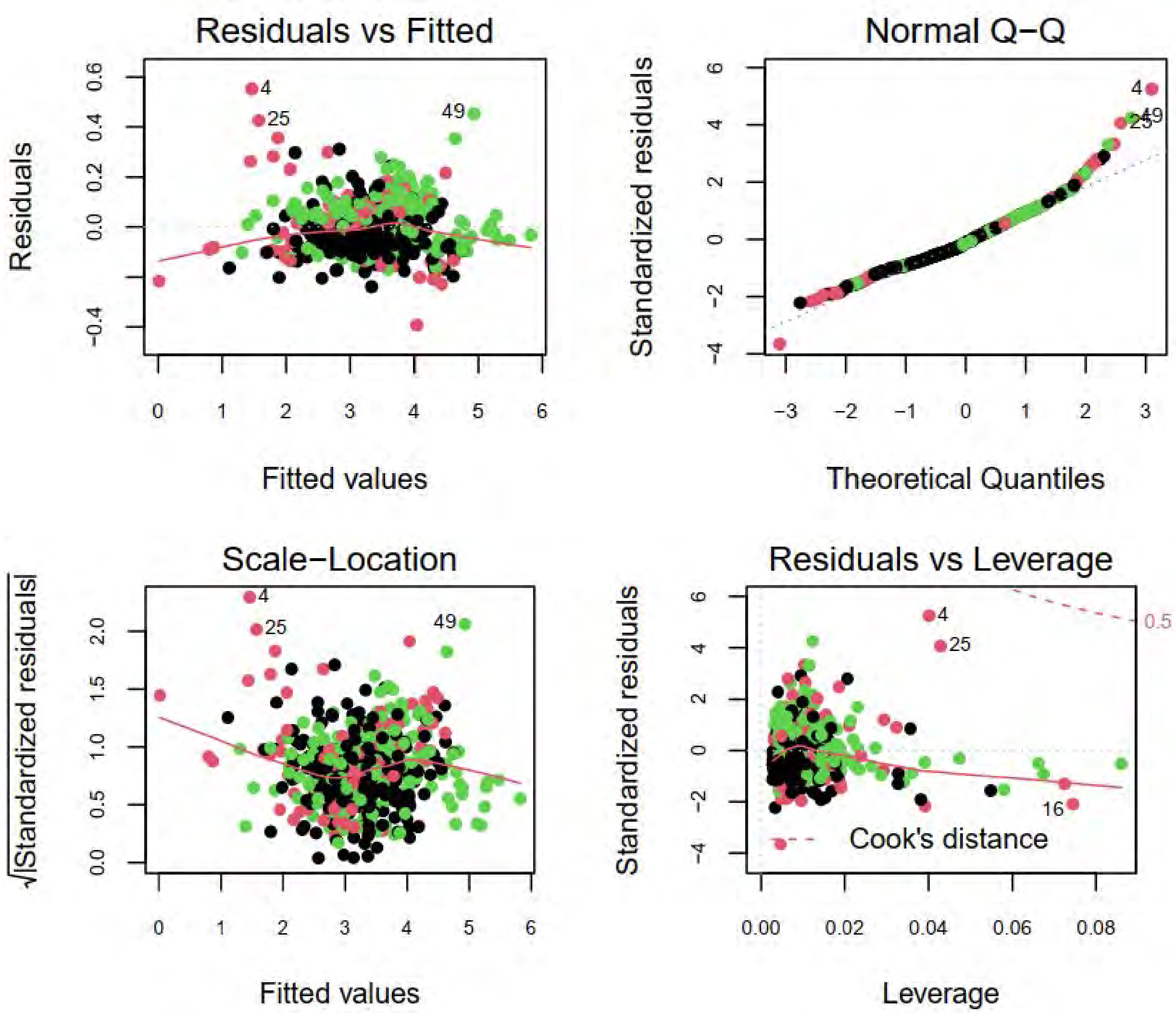
From a practical standpoint, the parsimonious Model 5 does not change the predictions of WQC exceedances when compared to the more complex models (Figure B2) and does not display any biases related to hydrology or watershed.

B5 Model Validation

Even for robust models with strong fits, like those presented in Section B4, there is inherent uncertainty associated with any MLR. This section provides a discussion of investigations into model uncertainties associated with the proposed acute and chronic copper SSWQC (Tables B7 and B8).

B5.1 Initial Model Diagnostics

Once the final MLRs were developed and proposed (Tables B7 and B8), several visual and statistical diagnostic procedures were carried out to evaluate those final models. Figure B3 provides diagnostic plots generated to evaluate the final acute MLR. The relationships shown in Figure B3 are comparable to those observed for the final chronic MLR.



Note: Figures are described in the text. Although hydrologic classifications were not included in the final MLR, the various classes are shown as colors in Figure B3: ephemeral/intermittent = black, intermittent = red, and ephemeral = green. Fitted and residual values are on a natural-log scale. The numbered points on plots correspond to potential outliers; the numbers correspond to the samples' indices within R (arbitrary ordering).

Figure B3. Model diagnostic plots for the proposed acute copper SSWQC

Figure B3 presents four diagnostic plots. The upper- and lower-left panes show MLR residuals versus the "fitted values," the natural-log of acute BLM WQC. The lines through the points indicate that there are minor trends in residuals toward the extremes of the data; however, the vast majority of data points are evenly spread around a residual of zero.

The top-right pane of Figure B3 shows a normal Q-Q plot, which is a way to visualize normality of residuals and to identify multiple populations within a distribution. A perfectly normal distribution would align with the dashed line. In general, the data align well with the dashed line, deviating from normality primarily at the upper end. This suggests that the residuals are approximately normal, but that there is some skewedness toward the extremes of the residuals (also visible as high residuals in the top-left pane). In this application, however, the deviation of residuals from normality is a minor uncertainty because the assumption of normal residuals is considered to be relatively unimportant when estimating values (e.g., BLM WQC) with linear models (Gelman and Hill 2006). The assumption of normality is important, however, when considering confidence intervals (not calculated herein) or conducting statistical tests (e.g., p-values for coefficients), neither of which were relied upon heavily to develop MLRs. Therefore, the proposed SSWQC can be used with a high degree of confidence despite minor uncertainties.

In the bottom-right pane of Figure B3, the influence of individual points is quantified using the leverage and standardized residual statistics. A Cook's distance level of 0.5 is overlaid on the figure as a dashed line, defining a general threshold for points with excessive leverage and residuals. Because no points occur beyond that threshold, no single point is considered to significantly influence the regression. This is perhaps unsurprising given how many data points are in the underlying dataset (n = 517), which makes the MLR robust despite extreme values. The points with highest leverage appear to be the perennial location samples identifiable in the top-left pane; the overall influence of the samples is low because their residual values are low.

The information provided by Figure B3 leads to the conclusion that the final acute MLR is reasonable but with some degree of model uncertainty related to groups of high residuals toward the extremes of the distribution (which are not likely "outliers" and so should be retained in the model). Considering of the strong relationship between the BLM WQC and MLR predictions (e.g., adjusted and predicted R^2 values of 0.980) and the reasonable appearance of residuals, the MLR models can be used with confidence to predict BLM WQC. This conclusion is further supported by evaluations presented in Sections 5.4.2 and 5.5 of the main text, which found MLR- and BLM-based WQC were highly comparable 1) for samples comprising the BLM dataset for the Pajarito Plateau (e.g., BLM-observed versus MLR-predicted WQC presented in Figure 5-5 of the main text); 2) across a wide range and combination of water quality conditions (e.g., Figure 5-6 of the main text); and 3) accordingly, for exceedance ratios calculated with either the BLM or MLR equation yield (e.g., Figure 5-7 of the main text).

B5.2 SENSITIVITY ANALYSIS

In addition to evaluating the potential influence of hydrologic classification on the MLR, other possible factors were considered: fire-related effects caused by the Las Conchas Fire of 2011, land use effects related to urbanization, and hydrologic classification status revised using more recent hydrology protocol data.

B5.2.1 Fire effects

Additional evaluation of the potential effects of fire was conducted. This was accomplished by visualizing the BLM- and MLR-based WQC data and color-coding the data points according to whether a location was potentially impacted by the Las Conchas Fire of 2011. Figure B4 shows this for the BLM- and MLR-based WQC comparison, and Figure B5 shows the comparison of BLM- and MLR-based exceedance ratios. Functionally, the figures indicate whether there is systematic bias in the prediction of fire-affected samples compared with the prediction of samples that were not fire affected. Samples with no classification with respect to potential fire effects (n = 13) were excluded from these comparisons.

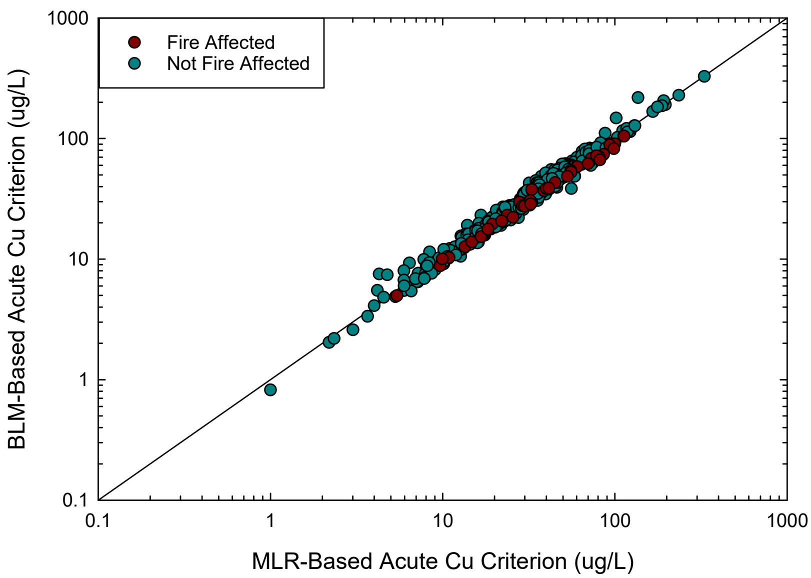


Figure B4. Comparison of BLM- and MLR-based WQC with respect to potential fire effects

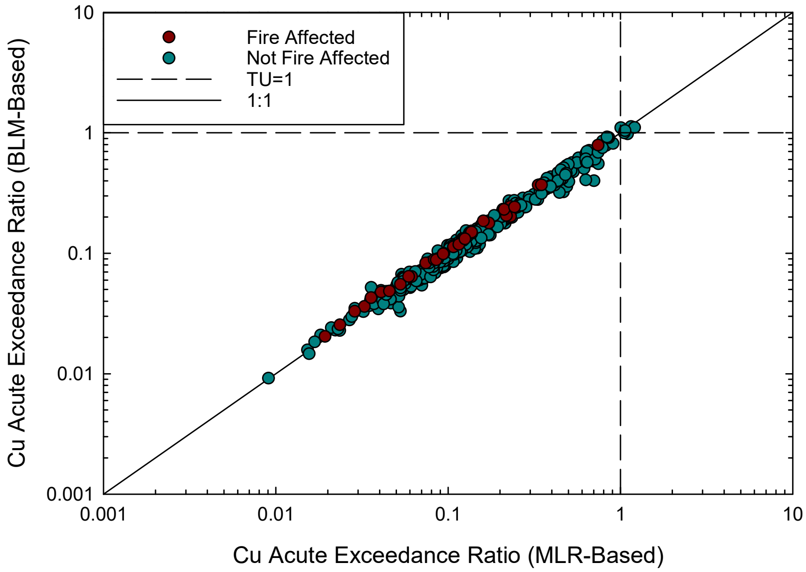


Figure B5. Comparison of BLM- and MLR-based exceedance ratios with respect to potential fire effects

Figures B4 and B5 illustrate several points:

- The relationship between the MLR- and BLM-based WQC and exceedance ratios is very strong; all points are close to the 1:1 line.
- The majority of samples were collected in watersheds (or at times) unimpacted by the Las Conchas Fire.
- WQC and exceedance ratios from fire-affected samples fall throughout the range of unaffected data, with only a few samples being relatively high; this applies to both the MLR- and BLM-based WQC and exceedance ratios.
- There does not appear to be a systematic bias in predictions, in that all points are spread evenly around the 1:1 line.

Based on these figures and evaluations of residual values described in Section B2.1, potentially fire-affected surface water samples do not have a substantial influence on MLR development, and the final MLR equation predicts potentially fire-affected samples and non-affected samples equally well.

B5.2.2 Land use effects

Similar to the evaluation of fire effects in Section B2.2, this section describes the evaluation of potential effects of land use. BLM- and MLR-based WQC data were color-coded according to whether a sample was collected from a location classified as "undeveloped" or "developed" (i.e., downstream of a LANL Resource Conservation and Recovery Act [RCRA] site). Figure B6 shows the color-coding results for the BLM-and MLR-based WQC comparison, and Figure B7 shows the comparison of BLM- and MLR-based exceedance ratios.

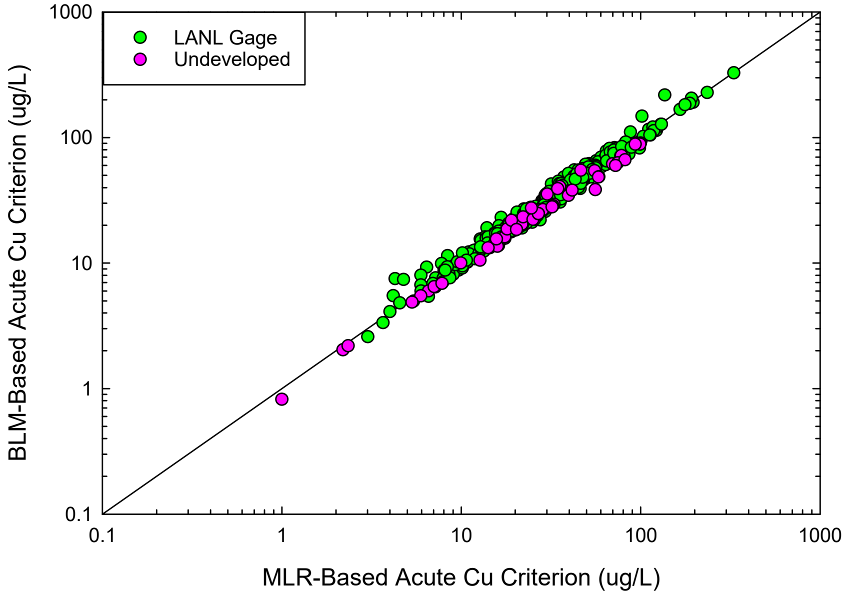


Figure B6. Comparison of BLM- and MLR-based WQC with respect to land use classifications

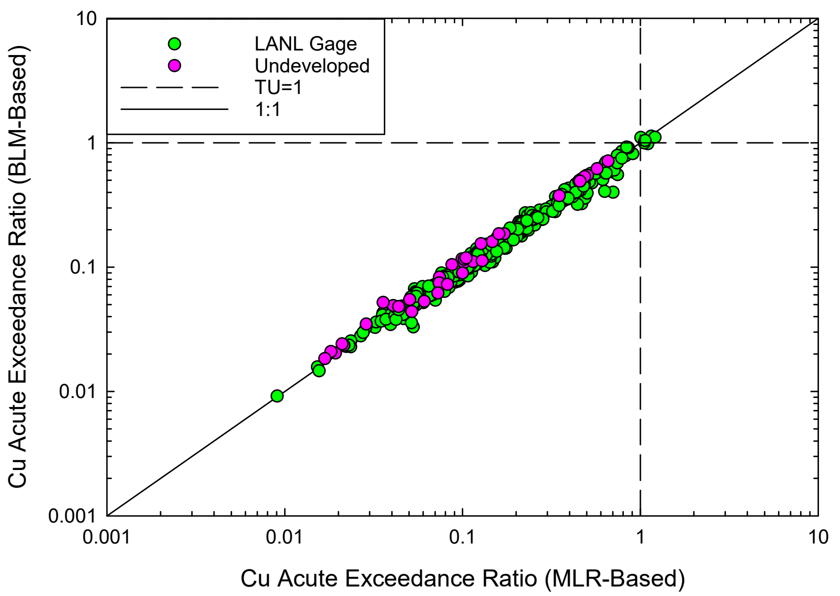


Figure B7. Comparison of BLM- and MLR-based exceedance ratios with respect to land use classification

Figures B6 and B7 illustrate several points:

- The relationship between the BLM- and MLR-based WQC and exceedance ratios is very strong; points are close to the 1:1 line.
- The majority of samples were collected downstream of LANL RCRA sites.
- BLM- and MLR-based WQC and exceedance ratios from samples collected in undeveloped locations fall throughout the ranges observed for developed locations in the BLM dataset for the Pajarito Plateau.
- There does not appear to be a systematic bias in predictions, in that all points are spread evenly around the 1:1 line.

Based on this figure and evaluations of residual values described in Section B2.1, undeveloped surface water samples do not have a substantial influence on MLR development, and the final MLR equation predicts both undeveloped and developed sample locations equally well.

B5.2.3 Alternate hydrological classifications

Section B4.2 provides a detailed evaluation of MLR models that consider current NMAC hydrologic classifications. Over the past several years, additional hydrology surveys of surface waters on the Pajarito Plateau have been conducted by NMED and the Laboratory; these surveys may lead to updated hydrology-based classifications (e.g., ephemeral, intermittent, perennial) and corresponding aquatic life use designations (e.g., limited aquatic life, marginal warm water, warm water). When developing MLRs, these potential ("alternate") classifications were considered along with current NMAC classifications; this section provides a brief overview of those findings.

As noted in Section B4.2, NMAC hydrologic classifications did not improve MLR performance, so the proposed copper SSWQC equations exclude hydrology-specific parameters (e.g., slopes and intercepts). This result was entirely consistent with the outcome of models developed using alternate hydrologic classifications based on more recent hydrological surveys and information. Table B10 shows a tabular breakdown of samples by major watershed and alternate classifications.[15] The number of samples presented in Table B10 (n = 509) is fewer than that in Table B1 (n = 517); this reflects the removal of eight samples lacking a clearly defined alternate hydrologic classification.

[15] The potential alternate hydrology classifications were developed based on findings from recent surveys conducted by NMED and the Laboratory. The alternate classifications are preliminary but included as an additional scenario to evaluate the sensitivity of MLR equations to underlying hydrology-based classifications.

Table B10. Hydrological classifications assignments for the BLM dataset by major watershed

Major Watershed	Alternate Hydrological Classification			N by Watershed
	Ephemeral	Intermittent	Perennial	
Ancho	4	0	0	**4**
Chaquehui	3	0	0	**3**
Frijoles	0	0	8	**8**
Los Alamos/Pueblo	53	117	33	**203**
Mortandad	9	25	0	**34**
Pajarito	19	35	11	**65**
Sandia	2	6	149	**157**
Water/Cañon de Valle	4	0	31	**35**
N by Alternate Hydrological Classification	**94**	**183**	**232**	**509**

BLM – biotic ligand model

N – sample size

Table B11 provides a comparison of MLRs using alternate hydrological classifications to those used in the simpler MLR equation proposed for copper SSWQC equations (i.e., Model 5, excluding hydrology-specific terms). Including hydrology-specific terms increased the adjusted and predicted R^2 values by only by 0.003 (after considering pH, DOC, and hardness). This is the same negligible change observed when comparing models with and without NMAC classification-specific parameters (Table B8). Thus, the same conclusion was reached regarding hydrology classifications: They are not necessary in the development of MLR equations to predict BLM-based WQC accurately and precisely for surface waters on the Pajarito Plateau. This conclusion is illustrated further in Figure B8.

Table B11. Summary statistics of MLR models developed using alternate hydrologic classifications

Model Description[a]		Adjusted R^2	Predicted R^2	AIC	BIC	Shapiro-Wilk Test p-value[b]	Scores Test p-value[c]
Model 3: hydrology-specific slopes and intercepts, with pH^2 terms	full	0.983	0.982	-909	-841	<0.0001	0.215
	AIC	0.983	0.982	-909	-841	<0.0001	0.215
	BIC	0.983	0.983	-906	-855	<0.0001	0.418
Model 4: hydrology-specific intercepts only	full	0.981	0.981	-848	-814	<0.0001	0.0264
	AIC	0.981	0.981	-848	-814	<0.0001	0.0264
	BIC	0.981	0.981	-848	-814	<0.0001	0.0264
Model 5: no hydrology-specific parameters	full	0.980	0.980	-823	-797	<0.0001	0.0839

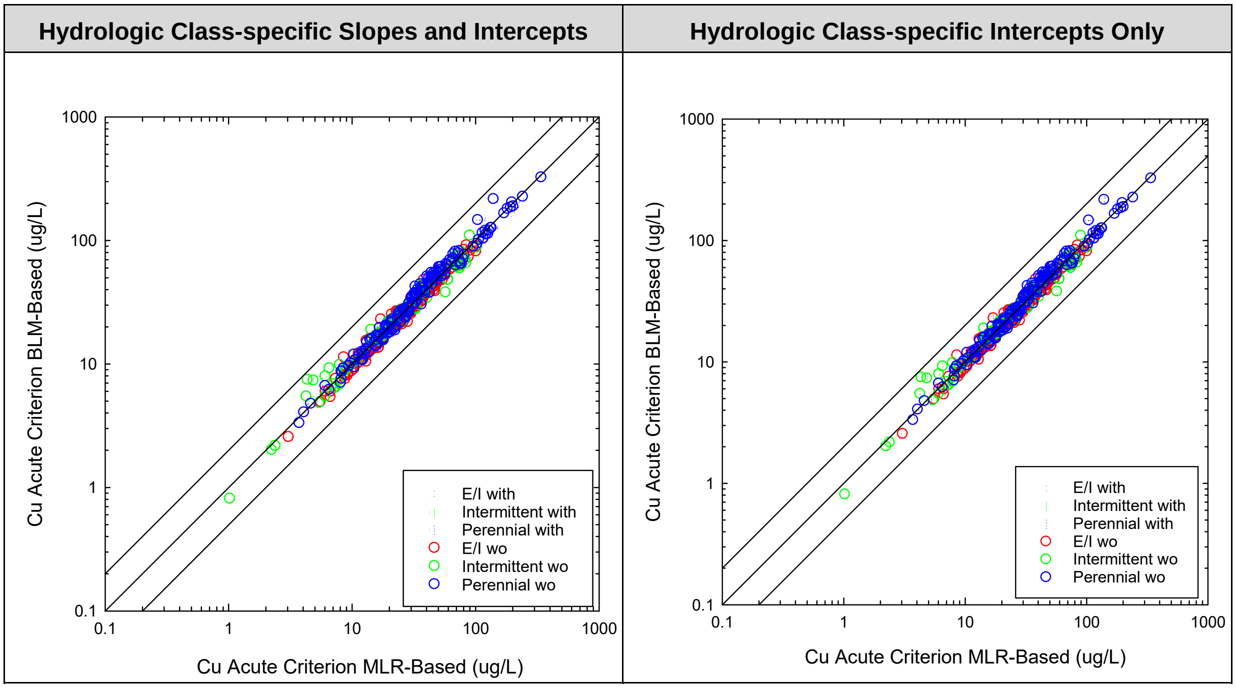
[a] Model descriptions are identified according to the key differences in model structure (left column) and the approach used to generate the model (right column). See Section B4.2 for more details.

[b] Shapiro-Wilk test for normality of residuals; $p < 0.05$ indicates non-normality.

[c] Score test for homogeneity of residuals; $p < 0.05$ indicates heteroscedasticity.

AIC – Akaike's Information Criterion BIC – Bayesian Information Criterion BLM – biotic ligand model MLR – multiple linear regression

Figure B8 shows a comparison of acute BLM- and MLR-based WQC with and without alternate hydrology terms included in the MLR equations. Consistent with the evaluation presented in Section B4.2, this figure shows very small or negligible changes resulting from the inclusion or exclusion of hydrology-specific terms.



Note: Closed circles indicate the values predicted by the MLR with hydrologic-specific classification; open circles are predictions after removing hydrologic classification parameters from the MLR; solid line is the 1:1 line..

Figure B8. Comparison of acute BLM-based WQC to MLR-based WQC with and without alternate hydrologic-specific MLR terms

B5.2.4 Predicted DOC uncertainty evaluation

As noted in Section B2.2, DOC was predicted from TOC for 124 samples that were used to develop MLRs. The development of a site-specific DOC-to-TOC ratio led to uncertainty resulting from DOC values exceeding TOC values in a subset of samples. To evaluate this uncertainty, two alternate methods for developing the MLR were investigated. The first method excluded all samples without measured DOC data, so no predictions of DOC were included in the alternate model, the results of which were then compared to results based on the final proposed model (Sections B4 and B6). The second method applied the New Mexico stream-specific default DOC-to-TOC conversion factor reported by EPA (2007) (0.815) instead of the site-specific value from Pajarito Plateau data (0.857). This change also affected the BLM output data used to develop the MLR, because DOC is one of the inputs to the BLM. Sections B5.2.4.1 and B5.2.4.2 respectively describe the outcomes of these two uncertainty evaluations.

B5.2.4.1 Alternate MLR investigation: no predicted DOC

The Model 5 structure (Section B4.2) was applied to the MLR dataset (as described in Section 5 of the main text) without the 124 samples for which DOC was predicted (Appendix A). The resulting model (based on 392 samples and the BLM acute Criterion Maximum Concentration [CMC] input) is described in Table B12.

Table B12. Alternate Model 5 MLR, no predicted DOC

Model Parameter	Model Coefficient	Standard Error	Coefficient Significance (p-value)
Intercept	-23.12523	1.05177	<0.001
DOC slope	1.05511	0.01026	<0.001
Hardness slope	-0.01473	0.01045	0.159
pH slope	5.24968	0.28402	<0.001
pH^2 slope	-0.26496	0.01925	<0.001
Adjusted R^2	**0.981**		
Predicted R^2	**0.980**		

Note: Model structure based on Model 5 (Equation 1 in the main document).

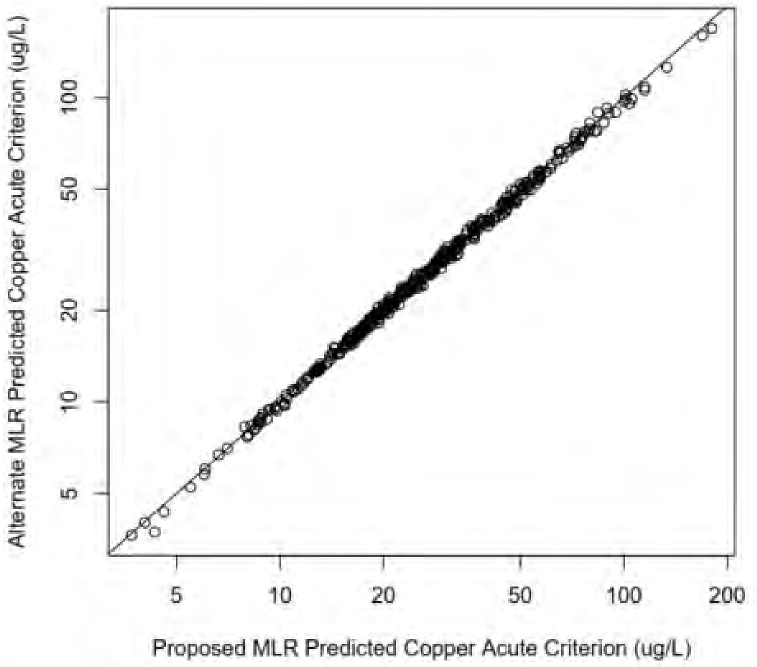
DOC – dissolved organic carbon

MLR – multiple linear regression

The alternate model is not substantially different from the proposed MLR model; for example, coefficients in the alternate model are reasonably similar to those in the model described in Table B7, and the two model fits are nearly identical. One key exception is the lack of significance of hardness in the alternate model. Significance (i.e., p-values) depends in part on sample size, so the loss of significance is not unexpected when the underlying sample size decreases by 24%.

BLM criteria were predicted using the alternate model and compared to predictions made using the proposed MLR model. Predictions are similar, tracking a 1:1 line reasonably closely (Figure B9). Although predictions tend to be lower for the alternate model (60% of 392 samples), these differences are slight. For example, the mean and median differences between predictions are 0.47 and 0.16 µg/L, respectively, and the mean and median absolute differences (as a percent)[16] are 2.4 and 2.0%. These differences are small (i.e., roughly 2%)—as shown by Figure B9—so the inclusion of predicted DOC values in the proposed MLR is not expected to have a substantive effect on MLR predictions.

[16] These differences were calculated as the average or median of the absolute value of differences between predicted acute BLM criteria divided by the prediction for the proposed MLR model (times 100%).



Note: line represents the 1:1 agreement between model predictions

Figure B9 Comparison of BLM model predictions to proposed MLR and alternate MLR model predictions using no predicted DOC samples

B5.2.4.2 Alternate MLR Investigation: EPA (2007) New Mexico DOC Prediction

The Model 5 structure (Section B4.2) was again applied to a revised dataset wherein DOC was predicted from TOC using a conversion factor of 0.815, and wherein BLM outputs (i.e., CMCs) were re-calculated using the alternate DOC inputs. The resulting model (based on 517 samples) is described in Table B13.

Table B13. Alternate Model 5 MLR, EPA (2007) New Mexico DOC prediction

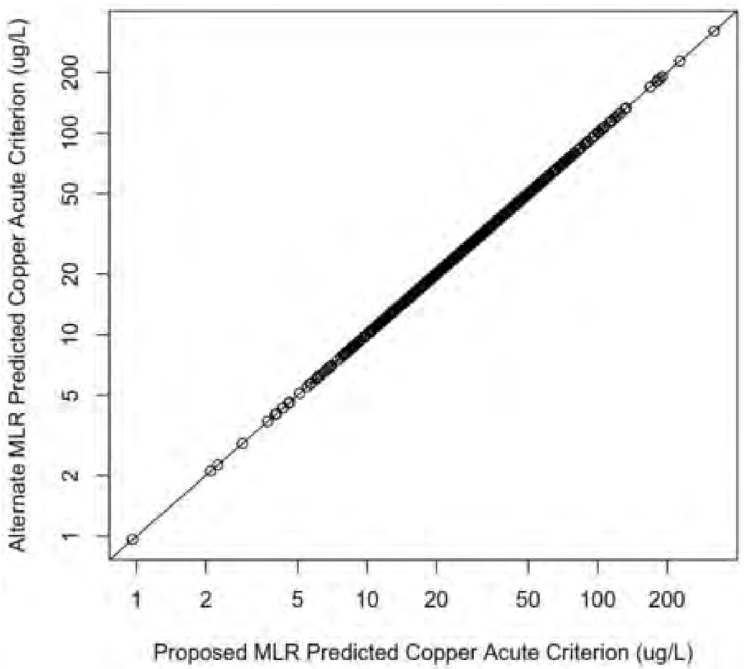
Model Parameter	Model Coefficient	Standard Error	Coefficient Significance (p-value)
Intercept	-22.880963	0.892724	<0.001
DOC slope	1.015665	0.008313	<0.001
Hardness slope	0.045126	0.009198	<0.001
pH slope	5.168510	0.236338	<0.001
pH^2 slope	-0.260276	0.015765	<0.001
Adjusted R^2	**0.980**		
Predicted R^2	**0.979**		

Note: Model structure based on Model 5 (Equation 1 in the main document).

DOC – dissolved organic carbon

MLR – multiple linear regression

This alternate model is very similar to the proposed MLR model (Table B7) in terms of coefficients, significance, and model fit. By extension, BLM criterion predictions are also very similar, as shown in Figure B10. The mean and median absolute differences between model predictions (as a percent) are 0.076% and 0.057%, respectively. There is no bias toward more or less conservative criterion predictions. In sum, the use of a lower DOC-to-TOC conversion factor would have a negligible effect on the MLR.



Note: Line represents the 1:1 agreement between model predictions.

Figure B10 Comparison of BLM model predictions to proposed MLR and alternate MLR model predictions using New Mexico DOC-to-TOC conversion factor

B6 Conclusions and Recommended copper SSWQC

Over the past 40 years, the scientific understanding of metal toxicity and bioavailability to aquatic organisms and the corresponding environmental regulations have increased. EPA has revised nationally recommended copper WQC from a simple linear equation based on hardness to a mechanistic model (the copper BLM) that incorporates several additional parameters. The BLM provides an improved method for setting copper WQC because it more accurately accounts for the modifying effect of site-specific water chemistry than do hardness-based equations (EPA 2007). Accordingly, the BLM was used to develop copper SSWQC for surface waters of the Pajarito Plateau.

Streams on the Pajarito Plateau are thoroughly monitored under a variety of EPA and NMED programs, so it is a suitable setting for developing BLM-based WQC.

The BLM dataset for the Pajarito Plateau (Appendix A) was generated from long-term monitoring data (Section 3.4 of the main text) and spans a wide range of surface water conditions. The current evaluation demonstrates that pH, DOC, and hardness concentrations account for 98% of the variation in BLM-based WQC. Potential refinements based on land use, fire effects, or hydrology were evaluated but did not result in a more accurate MLR equation.

Given these findings, the copper BLM can be simplified into a three-parameter MLR equation without losing a significant amount of accuracy and retaining the scientific rigor afforded by the BLM. The high degree of agreement between the acute and chronic MLRs and the BLM indicates that the equations presented in Section B6.1 can be adopted as copper SSWQC to provide accurate criteria that are protective of aquatic life in surface waters of the Pajarito Plateau, consistent with EPA recommendations and New Mexico WQS (20.6.4.10 NMAC).

B6.1 Proposed Copper SSWQC and Applicability

MLR equations were developed for both acute and chronic copper SSWQC for application to surface waters of the Pajarito Plateau.

The proposed acute SSWQC is as follows:

$$SSWQC_{acute} = exp(-22.914 + 1.017 \times ln(DOC) + 0.045 \times ln(hardness) + 5.176 \times pH - 0.261 \times pH^2)$$

The proposed chronic SSWQC is as follows:

$$SSWQC_{chronic} = exp(-23.391 + 1.017 \times ln(DOC) + 0.045 \times ln(hardness) + 5.176 \times pH - 0.261 \times pH^2)$$

As described in Section 3.3 of the main text, the Pajarito Plateau comprises ephemeral, intermittent, and perennial surface waters. Through the MLR development process, it was determined that hydrologic classifications did not influence the ability of the proposed acute and chronic SSWQC to accurately generate BLM-based WQC. Therefore, the acute and chronic copper SSWQC equations can be applied to any water body on the Pajarito Plateau. Most water bodies within the Laboratory's vicinity are classified as ephemeral or intermittent (20.6.4.128 NMAC); they are therefore designated as providing a limited aquatic life use and subject to acute WQC only. Other water bodies in the area are classified as perennial (20.6.4.126 and 20.6.4.121 NMAC) and are designated as providing higher-level aquatic life uses; these water bodies are subject to both acute and chronic aquatic life WQC. Unclassified surface water segments (20.6.4.98 NMAC) are designated as providing a marginal warm water aquatic life use and are subject to both acute and chronic WQC.

B7 References

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APPENDIX C. PUBLIC INVOLVEMENT PLAN

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Acronyms

BLM	biotic ligand model
EPA	US Environmental Protection Agency
LANL	Los Alamos National Laboratory
N3B	Newport News Nuclear BWXT-Los Alamos, LLC
NMED	New Mexico Environment Department
SSWQC	site-specific water quality criteria
SWQB	Surface Water Quality Bureau
Windward	Windward Environmental LLC
WQC	water quality criteria
WQCC	Water Quality Control Commission

C1 Introduction

On behalf of Newport News Nuclear BWXT-Los Alamos, LLC (N3B), Windward Environmental LLC (Windward) has prepared this Public Involvement Plan (hereinafter referred to as the Plan) to provide a process for public, tribal, and stakeholder engagement on the development of copper site-specific water quality criteria (SSWQC) for surface waters of the Pajarito Plateau in Los Alamos County, New Mexico. The Plan identifies the information, activities, and schedule needed to solicit participation from the various entities.

C1.1 BACKGROUND

Copper SSWQC are being developed for the Pajarito Plateau in accordance with the US Environmental Protection Agency's (EPA's) nationally recommended copper water quality criteria (WQC) for the protection of aquatic life (EPA 2007). The approach utilizes EPA's copper biotic ligand model (BLM), which incorporates the effects of multiple water chemistry parameters on the bioavailability and toxicity of copper. EPA considers the copper BLM to represent the best available science for setting copper WQC (EPA 2007, 700258). The physical and chemical characteristics (i.e., BLM parameters) of Pajarito Plateau surface waters have been rigorously monitored at a variety of locations, so the Pajarito Plateau is a suitable setting for BLM-based copper SSWQC.

C1.2 OBJECTIVES

This Plan provides a general process and schedule for public, tribal, and stakeholder involvement in the development of copper SSWQC for waters of the Pajarito Plateau. Specific objectives are as follows:

- Identify potential stakeholders, tribes, and sections of the public that may be affected by the proposed copper SSWQC (Section C2).
- Establish a process to present the proposed copper SSWQC to stakeholders, tribes, and the general public, and to receive and respond to input (Section C3).
- Develop a draft schedule with milestones for stakeholder, tribal, and public engagement (Section C4).

C2 Stakeholders, Tribes, and the Public

Key stakeholders, tribes, and the public are identified in this section. These groups are the targets for involvement outreach, and it is expected that several groups from these targets will engage in the activities described in Section C3.

C2.1 POTENTIAL STAKEHOLDERS

Potential stakeholders are non-tribal public entities, agencies, and natural resource trustees that may be directly impacted by the proposed copper SSWQC. Their input will be solicited separately from public and tribal input.

Potential stakeholders include:

- New Mexico Environment Department (NMED) Surface Water Quality Bureau (SWQB)
- EPA Region 6
- US Bureau of Land Management
- US Forest Service
- National Park Service
- Los Alamos County
- Santa Fe County
- Eastern Jemez Resource Council
- Northern New Mexico's Citizen's Advisory Board
- Buckman Direct Diversion

This list is not necessarily comprehensive and may change in response to feedback from NMED SWQC and EPA Region 6.

C2.2 TRIBES

Tribal outreach is intended to involve leadership/representatives of local pueblos; these engagements will be separate from stakeholder and public engagements. All tribal members will be welcome to attend public engagements as well. Local pueblos identified for outreach include:

- San Ildefonso Pueblo
- Santa Clara Pueblo
- Cochiti Pueblo
- Jemez Pueblo

This list is not necessarily comprehensive and may change in response to feedback from NMED SWQB and EPA Region 6.

C2.3 General Public

The public includes any individuals on or around the Pajarito Plateau, including but not limited to those living in and near Los Alamos County, Cochiti Lake, San Ildefonso Pueblo, Santa Clara Pueblo, Cochiti Pueblo, and Jemez Pueblo. Public engagements will be open to all who wish to attend, and members of the public will have the right to provide comments on the draft SSWQC demonstration report.

C3 Planned Activities

There are 16 activities associated with the public involvement process: 13 to be conducted by Windward and N3B, and 3 to be conducted by stakeholders, tribes, and the public. Activities to be conducted by Windward or N3B include:

1. Submit draft work plan for developing copper SSWQC for review by NMED SWQB and EPA Region 6.[1]
2. Prepare response to NMED and EPA comments on the work plan.
3. Prepare and submit drafts of the copper SSWQC demonstration report for initial and final review by NMED and EPA.
4. Submit revised draft Demonstration Report, comment responses, and supporting data to NMES SWQB and EPA.
5. Prepare response to NMED SWQB and EPA comments on the Demonstration Report and revise the report accordingly.
6. Submit draft copper SSWQC demonstration report to appropriate physical locations for public review and host the digital version of the report on the N3B and Individual Permit (IP) Public websites; an abbreviated fact sheet describing the proposed SSWQC will also be hosted on the IP Public website (https://ext.em-la.doe.gov/ips) and on the N3B outreach website (https://n3b-la.com/outreach).
7. Notify the public of the open comment period (45 days) in local newspapers (the Santa Fe New Mexican, the Rio Grande Sun in Española, and the Los Alamos Daily Post), on the IP public website (https://ext.em-la.doe.gov/ips), on the N3B Cleanup Outreach website (https://n3b-la.com/outreach), and through direct communication with identified stakeholders (Section C2).

[1] This was complete as of September 9, 2020. NMED SWQB and EPA Region 6 provided comments to N3B on March 9, 2021.

[2] This was complete as of July 28, 2021.

[3] This was complete as of July 28, 2021. NMED SWQB and EPA Region 6 provided comments to N3B on November 9, 2021.

8. Hold a series of meetings in person and/or by webinar for stakeholders, tribes, and the public.
9. Review comments submitted via email to publiccomment@em-la.doe.gov.
10. Prepare formal response to public comments and append to the final copper SSWQC demonstration report.
11. Finalize and submit demonstration report to the New Mexico Water Quality Control Commission (WQCC) as part of a formal petition to change New Mexico's Water Quality Standards.

Stakeholders, tribes, and the public are to review documents, attend appropriate engagements, and submit comments via email to N3BOutreach@em-la.doe.gov.

C4 Schedule of Activities

Table C1 provides a tentative schedule of the activities listed in Section C3. The schedule shows the order of past and intended activities and their relative position over time. Specific dates are subject to change.

Table C1. Schedule of Past and Planned Activities

Activity	Acting Group(s)	Target Audience	Dates
Submit draft Work Plan	N3B/LANL	NMED SWQB and EPA Region 6	September 9, 2020
Receive NMED/EPA Region 6 comments on Work Plan	NMED SWQB and EPA Region 6	N3B/LANL	March 9, 2021
Respond to NMED/EPA comments on Work Plan	N3B/LANL	NMED SWQB and EPA Region 6	July 28, 2021
Submit draft Demonstration Report to NMED/EPA	N3B/LANL	NMED SWQB and EPA Region 6	July 28, 2021 (corrected August 20, 2022)
Submit revised draft Demonstration Report, comment responses, and supporting data to NMED/EPA	N3B/LANL	NMED SWQB and EPA Region 6	March 30, 2022 (report), April 18, 2022 (comment responses), and May 31, 2022 (additional materials upon NMED request)
Receive NMED/EPA comments on Demonstration Report	NMED SWQB and EPA Region 6	N3B/LANL	March 31, 2023
Prepare response to NMED and EPA comments on the Demonstration Report.	N3B/LANL	NMED SWQB and EPA Region 6	May to August 2023
Submit draft Demonstration Report	N3B/LANL	NMED SWQB and EPA Region 6	August 2023
Notify stakeholders, tribes, and public about copper SSWQC and comment period	N3B/LANL	stakeholders, tribes, and public	Estimated September to November 2023
Meet with stakeholders	N3B/LANL	stakeholders	Estimated September to November 2023

Activity	Acting Group(s)	Target Audience	Dates
Meet with tribes	N3B/LANL	tribes	Estimated September to November 2023
Hold public meeting	N3B/LANL	public	Estimated October 2023
Develop response to public comments	N3B/LANL	stakeholders, tribes, public, WQCC	Estimated October to December 2023
Finalize Demonstration Report	N3B/LANL	stakeholders, tribes, public, WQCC	Estimated January, 2024
File formal petition with final Demonstration Report and response to comments	N3B/LANL	WQCC	Estimated January, 2024

EPA – Environmental Protection Agency
LANL – Los Alamos National Laboratory
N3B – Newport News Nuclear BWXT Los Alamos
NMED – New Mexico Environment Department
SWQB –Surface Water Quality Bureau
SSWQC – site-specific water quality criteria
WQCC – Water Quality Control Commission

C5 Reference

EPA (U.S. Environmental Protection Agency), February 2007. “Aquatic Life Ambient Freshwater Quality Criteria - Copper,” 2007 Revision, EPA-822-R-07-001, Office of Water, Office of Science and Technology, Washington, D.C. (EPA 2007, 700258)

APPENDIX D. THREATENED AND ENDANGERED SPECIES CONSIDERATIONS

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Table D-1. Rio Grande copper concentrations and water quality criteria 3

Acronyms

AWQC	ambient water quality criteria
BLM	biotic ligand model
DOC	dissolved organic carbon
EPA	US Environmental Protection Agency
ESA	Endangered Species Act
ID	identification
MLR	multiple linear regression
NMFS	National Marine Fisheries Service
SSWQC	site-specific water quality criteria
T&E	threatened and endangered
TU	toxic unit
USFWS	US Fish and Wildlife Service
WQC	water quality criteria

D1 Overview

This appendix identifies threatened and endangered (T&E) species that may occur on or in the vicinity of the Pajarito Plateau. It also discusses the protectiveness of the proposed copper site-specific water quality criteria (SSWQC) to these species.

In accordance with Section 7 of the federal Endangered Species Act (ESA), the Environmental Protection Agency (EPA) consults with the US Fish and Wildlife Service (USFWS) to ensure that any action[1] authorized by the EPA is not likely to jeopardize the continued existence of T&E species or result in the destruction or adverse modification of T&E species or their critical habitats. In the context of this SSWQC proposal, such action would include adoption of EPA's national recommended ambient water quality criteria (AWQC) for copper (EPA 2007) as this is the basis of the proposed copper SSWQC. Importantly, the proposed SSWQC is not associated with any new actions or discharges that would result in increased copper loading to surface waters of the Pajarito Plateau.

EPA's national recommended AWQC for the protection of aquatic life are derived from empirical toxicity data and are designed to be stringent enough to protect sensitive aquatic species potentially exposed to a contaminant in any water body in the United States. Below these thresholds, significant adverse effects on aquatic communities are not anticipated. In accordance with EPA guidelines (EPA 1985), AWQC are only developed if an eight-family rule is met, which requires toxicity results with at least one species in at least eight different families. The acute toxicity dataset used to derive EPA's national recommended AWQC for copper comprises empirical toxicity data for 39 species across 27 genera and 20 families.[2] As such, the database used to develop the copper AWQC represents a diverse group of aquatic species and, as discussed in this appendix, is expected to provide sufficient protection to both aquatic and terrestrial T&E species.

Sections D2 and D3 identify aquatic T&E species that may reside in surface waters downstream of the Pajarito Plateau and discuss how the SSWQC is protective of these species.

Sections D4 through D8 identify terrestrial T&E species that may reside in the vicinity of the Pajarito Plateau and discuss how the SSWQC is protective of these species.

[1] Under the ESA, an "action" includes all activities or programs of any kind authorized, funded, or carried out, in whole or in part, by Federal agencies in the United States. This includes promulgation of regulations, including oversight of State and tribal water quality criteria.

[2] As discussed in the main text, chronic AWQC are based on an acute-to-chronic ratio rather than a distinct chronic toxicity dataset; therefore, the chronic dataset also is composed of 39 species, 27 genera, and 20 families.

D2 Rio Grande Cutthroat Trout (*Oncorhynchus clarkii virginalis*)

The Rio Grande cutthroat trout is a subspecies of cutthroat trout (genus *Oncorhynchus*), the range of which spans the Rio Grande, the Pecos River, and the Canadian River drainages of southern Colorado and northern New Mexico (Pritchard and Cowley 2006). Populations are spatially restricted and fragmented, primarily confined to headwater streams and small high-elevation lakes. Cutthroat trout are opportunistic foragers that feed on aquatic and terrestrial invertebrates such as midge (Chironomidae) larvae, mayflies (Ephemeroptera), ostracods, caddisflies (Tricoptera), and other flies (Diptera) (RGCT Conservation Team 2013; Pritchard and Cowley 2006).

The SSWQC is intended to be protective of aquatic life species, including Rio Grande cutthroat trout and their prey. For example, the copper biotic ligand model (BLM) database includes acute and/or chronic toxicity test results for cutthroat trout (*O. clarkii*), Lahontan cutthroat trout (*O. clarkii henshawi*), and several other taxonomically similar salmonids (e.g., *Oncorhynchus* spp. and *Salmo* spp.).

Of the species included in the copper BLM database, salmonids are not the most sensitive. Therefore, the BLM (and, by extension, the SSWQC) is protective of salmonids as well as sensitive invertebrates, including potential prey items. In addition, the USFWS and the National Marine Fisheries Service (NMFS) previously concluded the copper BLM provides an improved level of protection to these salmonids relative to hardness-based water quality criteria (WQC) (NMFS 2014; USFWS 2015). Therefore, implementing the SSWQC is not expected to adversely affect Rio Grande cutthroat trout.

Copper concentrations in the Rio Grande were compared to copper WQC (Table D-1). In 110 samples collected at 5 separate sampling locations along the main stem of the Rio Grande near the Pajarito Plateau (i.e., Taos Junction Bridge, Otowi Bridge, Cochiti Dam, San Felipe, and Alameda Bridge) between 2005 and 2021, there were no exceedances of acute or chronic copper BLM-based criteria, proposed copper SSWQC, or New Mexico's current hardness-based criteria. These results show that moving from the hardness-based WQC to the proposed SSWQC would not adversely affect aquatic species in the Rio Grande downstream of the Pajarito Plateau.

Table D-1. Rio Grande copper concentrations and WQC

Location ID	Date	X	Y	Temp. (C)	Copper (µg/L)	pH	DOC (mg/L)	Hardness (mg/L CaCO3)	Ca (mg/L)	Mg	Na	K	Sulfate	Cl	Alkalinity (mg/L CaCO3)	BLM (ug/L) Acute	BLM (ug/L) Chronic	MLR SSWQC (ug/L) Acute	MLR SSWQC (ug/L) Chronic	New Mexico Hardness-based Criteria (ug/L) Acute	New Mexico Hardness-based Criteria (ug/L) Chronic	BLM Acute TU	BLM Chronic TU	MLR SSWQC Acute TU	MLR SSWQC Chronic TU	New Mexico Hardness-based Criteria Acute TU	New Mexico Hardness-based Criteria Chronic TU
Rio Grande below Taos Junction Bridge near Taos, NM	12/5/05	1054516	361912.12	1.5	1	8.5	1.02	87.7	26.8	5.06	14.5	2.63	24	4.57	171	9	6	12	7.1	12	8.3	0.11	0.18	0.08	0.14	0.08	0.12
Rio Grande below Taos Junction Bridge near Taos, NM	4/18/06	1054516	361912.12	13	1.9	8.8	1	93.1	27.4	6	19.1	2.91	33.2	5.89	194	14	8	14	8.5	13	8.8	0.14	0.23	0.14	0.22	0.15	0.22
Rio Grande below Taos Junction Bridge near Taos, NM	8/7/06	1054516	361912.12	22	0.92	8.6	1.92	85.8	25.2	5.57	20.2	3.29	28.8	5.71	195	27	17	24	15	12	8.2	0.03	0.05	0.04	0.06	0.08	0.11
Rio Grande below Taos Junction Bridge near Taos, NM	11/27/06	1054516	361912.12	4	0.78	8.5	1.4	72.3	21.9	4.3	13	2.51	19.4	3.76	151	12	8	16	9.7	10	7.1	0.06	0.10	0.05	0.08	0.08	0.11
Rio Grande below Taos Junction Bridge near Taos, NM	4/30/07	1054516	361912.12	15	3.4	8.5	8.6	119	35.2	7.49	27.4	3.79	74.4	7.84	207	100	62	103	63	16	11	0.03	0.05	0.03	0.05	0.21	0.31
Rio Grande below Taos Junction Bridge near Taos, NM	8/13/07	1054516	361912.12	21	2.6	8.2	4.15	59.7	17.6	3.84	11.3	2.45	19	3.12	139	37	23	37	23	8.6	6	0.07	0.11	0.07	0.11	0.30	0.43
Rio Grande below Taos Junction Bridge near Taos, NM	11/5/08	1054516	361912.12	9	2.6	8.4	1.22	100	29.1	6.66	19	2.95	33.1	6.38	218	12	7	13	7.9	14	9.3	0.22	0.36	0.20	0.33	0.19	0.28
Rio Grande below Taos Junction Bridge near Taos, NM	6/4/09	1054516	361912.12	15	1.2	8.1	5.99	142	42.9	8.7	29.9	4.65	94.2	7.37	205	50	31	51	31	20	13	0.02	0.04	0.02	0.04	0.06	0.09
Rio Grande below Taos Junction Bridge near Taos, NM	8/11/09	1054516	361912.12	19.5	0.8	8.7	2.05	104	30.8	6.68	21.9	2.95	41.5	6.67	210	31	19	27	17	15	9.7	0.03	0.04	0.03	0.05	0.05	0.08
Rio Grande below Taos Junction Bridge near Taos, NM	11/16/09	1054516	361912.12	7.2	1	8.6	1.38	103	30.1	6.66	17.9	2.93	35.1	5.81	211	14	9	17	10	14	9.5	0.07	0.11	0.06	0.10	0.07	0.11
Rio Grande below Taos Junction Bridge near Taos, NM	5/4/10	1054516	361912.12	12	1.3	8.3	4.49	91.4	28	5.25	14.3	2.81	36.3	4.29	158	39	24	45	27	13	8.6	0.03	0.05	0.03	0.05	0.10	0.15
Rio Grande below Taos Junction Bridge near Taos, NM	8/9/10	1054516	361912.12	20.8	1.1	8.7	1.63	108	31.9	7.02	20.2	3.06	39.6	6.45	210	25	16	22	13	15	10	0.04	0.07	0.05	0.08	0.07	0.11
Rio Grande at Otowi Bridge, NM	12/13/05	1060832.8	355228.2	2	1.5	8.4	1.58	123	38.7	6.39	18.4	2.72	33.6	6.1	224	14	9	17	10	17	11	0.11	0.18	0.09	0.15	0.09	0.14

Location ID	Date	X	Y	Temp. (C)	Copper (µg/L)	pH	DOC (mg/L)	Hardness (mg/L CaCO3)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Sulfate (mg/L)	Cl (mg/L)	Alkalinity (mg/L CaCO3)	BLM (ug/L) Acute	BLM (ug/L) Chronic	MLR SSWQC (ug/L) Acute	MLR SSWQC (ug/L) Chronic	New Mexico Hardness-based Criteria (ug/L) Acute	New Mexico Hardness-based Criteria (ug/L) Chronic	BLM Acute TU	BLM Chronic TU	MLR SSWQC Acute TU	MLR SSWQC Chronic TU	New Mexico Hardness-based Criteria Acute TU	New Mexico Hardness-based Criteria Chronic TU
Rio Grande at Otowi Bridge, NM	4/19/06	1060832.8	355228.2	12	1.6	8.4	1.75	109	34	5.81	16.1	2.39	36.7	5.11	195	17	11	19	12	15	10	0.09	0.15	0.08	0.13	0.11	0.16
Rio Grande at Otowi Bridge, NM	8/8/06	1060832.8	355228.2	24.5	1.3	8.2	2.07	115	36.9	5.49	19	3.75	34.9	6.45	244	22	14	19	12	16	10	0.06	0.10	0.07	0.11	0.08	0.13
Rio Grande at Otowi Bridge, NM	11/28/06	1060832.8	355228.2	5.5	0.78	8.4	0.73	93.2	28.7	5.25	14.8	2.38	31.5	4.61	186	7	4	7.6	4.7	13	8.8	0.12	0.19	0.10	0.17	0.06	0.09
Rio Grande at Otowi Bridge, NM	5/1/07	1060832.8	355228.2	16	1.8	8.4	6.7	107	32.9	6	19.4	2.76	51.4	6.31	198	70	44	73	45	15	9.9	0.03	0.04	0.02	0.04	0.12	0.18
Rio Grande at Otowi Bridge, NM	8/14/07	1060832.8	355228.2	23	1.5	8.2	3.74	94.7	29.5	5.13	14.2	2.18	33.4	3.79	188	36	23	34	21	13	8.9	0.04	0.07	0.04	0.07	0.12	0.17
Rio Grande at Otowi Bridge, NM	11/20/07	1060832.8	355228.2	7.5	0.8	8.5	1.07	99.1	30.2	5.78	18.3	2.79	29.8	5.85	213	11	7	12	7.5	14	9.3	0.08	0.12	0.07	0.11	0.06	0.09
Rio Grande at Otowi Bridge, NM	11/7/08	1060832.8	355228.2	4	0.64	8.3	2.32	130	39.7	7.56	21.9	2.84	39.9	8.01	273	20	12	23	14	18	12	0.03	0.05	0.03	0.05	0.04	0.05
Rio Grande at Otowi Bridge, NM	5/6/09	1060832.8	355228.2	11	1.8	8.1	6.78	82.9	26.2	4.25	9.91	1.98	30.5	2.7	141	48	30	57	35	12	7.9	0.04	0.06	0.03	0.05	0.15	0.23
Rio Grande at Otowi Bridge, NM	8/13/09	1060832.8	355228.2	19.5	0.86	8.1	4.18	115	37.2	5.44	13.2	2.11	47.1	3.19	191	35	22	35	22	16	11	0.02	0.04	0.02	0.04	0.05	0.08
Rio Grande at Otowi Bridge, NM	11/17/09	1060832.8	355228.2	6.5	0.56	8.5	2.06	127	39.5	6.88	20.5	2.68	39.5	6.88	244	20	13	24	15	18	11	0.03	0.04	0.02	0.04	0.03	0.05
Rio Grande at Otowi Bridge, NM	5/6/10	1060832.8	355228.2	11	1	8.2	4.28	99.3	31.3	5.15	12.3	2.06	37.6	3.45	164	34	21	39	24	14	9.3	0.03	0.05	0.03	0.04	0.07	0.11
Rio Grande at Otowi Bridge, NM	8/11/10	1060832.8	355228.2	20.3	0.9	8.2	3.28	118	37.4	5.98	12.7	2.07	39	3.97	204	31	19	30	19	16	11	0.03	0.05	0.03	0.05	0.06	0.08
Rio Grande below Cochiti Dam, NM	11/19/09	1061926.2	353704.8	9.7	0.5	8.2	2.44	122	38.5	6.29	18	2.65	39.3	5.92	236	20	12	22	14	17	11	0.03	0.04	0.02	0.04	0.03	0.05
Rio Grande below Cochiti Dam, NM	5/10/10	1061926.2	353704.8	12.7	1.2	8.2	4.52	92.4	29.4	4.62	11.8	2.1	33.8	3.49	162	36	22	41	25	13	8.7	0.03	0.05	0.03	0.05	0.09	0.14
Rio Grande below Cochiti Dam, NM	8/16/10	1061926.2	353704.8	22.7	0.79	7.8	3.56	121	39	5.64	14.4	2.62	37.9	4.33	213	23	14	22	14	17	11	0.04	0.06	0.04	0.06	0.05	0.07
Rio Grande below Cochiti Dam, NM	12/2/10	1061926.2	353704.8	6.2	0.56	8.2	2.05	122	38.2	6.44	18.4	2.66	38	5.74	242	16	10	19	11	17	11	0.03	0.06	0.03	0.05	0.03	0.05
Rio Grande below Cochiti Dam, NM	6/2/11	1061926.2	353704.8	16.4	0.73	8.2	3.52	119	37	6.49	16	2.48	44.3	4.64	204	31	19	32	20	16	11	0.02	0.04	0.02	0.04	0.05	0.07
Rio Grande below Cochiti Dam, NM	8/12/11	1061926.2	353704.8	23.1	0.56	7.9	3.8	99.9	31	5.49	13.1	2.97	34.2	3.44	181	26	16	26	16	14	9.3	0.02	0.03	0.02	0.04	0.04	0.06
Rio Grande below Cochiti Dam, NM	12/7/11	1061926.2	353704.8	5.6	0.8	8	2.2	105	32.5	5.71	15.3	2.51	31.6	5.14	204	14	9	16	10	15	9.7	0.06	0.09	0.05	0.08	0.05	0.08
Rio Grande below Cochiti Dam, NM	4/25/12	1061926.2	353704.8	13.1	1.5	8	3.39	90.2	27.9	5.01	12.3	2.1	29.1	4.25	178	23	14	25	16	13	8.5	0.07	0.11	0.06	0.09	0.12	0.18
Rio Grande below Cochiti Dam, NM	8/22/12	1061926.2	353704.8	22.4	0.9	8.2	4.07	120	38.1	5.93	14.8	3.06	41.4	3.55	200	40	25	37	23	17	11	0.02	0.04	0.02	0.04	0.05	0.08
Rio Grande below Cochiti Dam, NM	12/18/12	1061926.2	353704.8	4.7	0.8	8.2	2.56	130	40.9	6.98	18.1	2.78	46.5	5.21	226	20	12	23	14	18	12	0.04	0.06	0.03	0.06	0.04	0.07
Rio Grande below Cochiti Dam, NM	5/9/13	1061926.2	353704.8	13.6	0.8	7.9	2.47	125	38.5	7	19.1	2.59	52.1	5.07	224	16	10	17	10	17	11	0.05	0.08	0.05	0.08	0.05	0.07
Rio Grande below Cochiti Dam, NM	8/1/13	1061926.2	353704.8	22.4	0.8	8	4.62	125	39.6	6.44	20.4	4.07	52	4.72	238	38	23	35	22	17	11	0.02	0.03	0.02	0.04	0.05	0.07
Rio Grande below Cochiti Dam, NM	12/17/13	1061926.2	353704.8	3.8	0.8	8.1	2.67	121	37.7	6.44	18.1	2.82	38.9	5.78	225	19	12	22	14	17	11	0.04	0.07	0.04	0.06	0.05	0.07
Rio Grande below Cochiti Dam, NM	5/12/14	1061926.2	353704.8	13.4	0.8	8.1	3.08	125	39.2	6.54	19.2	2.73	56.5	5.5	213	24	15	26	16	17	11	0.03	0.05	0.03	0.05	0.05	0.07

Location ID	Date	X	Y	Temp. (C)	Copper (µg/L)	pH	DOC (mg/L)	Hardness (mg/L CaCO3)	Ca	Mg	Na	K	Sulfate	Cl	Alkalinity (mg/L CaCO3)	BLM (ug/L)		MLR SSWQC (ug/L)		New Mexico Hardness-based Criteria (ug/L)		BLM		MLR SSWQC		New Mexico Hardness-based Criteria	
									(mg/L)							Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute TU	Chronic TU	Acute TU	Chronic TU	Acute TU	Chronic TU
Rio Grande below Cochiti Dam, NM	8/21/14	1061926.2	353704.8	22.3	1.4	7.9	3.37	121	38.8	5.81	16.2	3.57	41	4.18	215	24	15	23	14	17	11	0.06	0.09	0.06	0.10	0.08	0.13
Rio Grande below Cochiti Dam, NM	1/5/15	1061926.2	353704.8	2.6	0.8	8.1	2.05	108	33.6	5.93	18.7	2.65	37.2	5.53	217	14	9	17	10	15	10	0.06	0.09	0.05	0.08	0.05	0.08
Rio Grande below Cochiti Dam, NM	3/28/15	1061926.2	353704.8	10.2	1.6	7.7	3.02	95.5	29.6	5.27	16.6	2.65	29.8	6.17	197	15	9	16	10	13	9	0.11	0.17	0.10	0.16	0.12	0.18
Rio Grande below Cochiti Dam, NM	8/11/15	1061926.2	353704.8	22.6	0.8	7.9	3.32	111	35	5.66	14.2	2.71	34.8	3.83	192	23	15	23	14	15	10	0.03	0.06	0.03	0.06	0.05	0.08
Rio Grande below Cochiti Dam, NM	1/25/16	1061926.2	353704.8	2.9	0.8	7.9	2.25	112	34.6	6.27	16.4	2.42	38.1	5.62	105	14	8	15	9	15	10	0.06	0.10	0.05	0.09	0.05	0.08
Rio Grande below Cochiti Dam, NM	5/25/16	1061926.2	353704.8	15.7	1.1	8.1	4.29	99	30.8	5.32	12.7	2.48	32.6	3.82	84	33	21	36	22	13	9	0.03	0.05	0.03	0.05	0.08	0.12
Rio Grande below Cochiti Dam, NM	8/25/16	1061926.2	353704.8	21.5	0.96	8	3.54	117	37.6	5.4	14.1	2.73	44	3.92	97.4	27	17	27	17	16	10	0.03	0.06	0.04	0.06	0.06	0.09
Rio Grande below Cochiti Dam, NM	12/12/16	1061926.2	353704.8	5.6	0.66	8.1	2.2	123	37.7	6.8	19	2.59	43.2	5.82	112	16	10	18	11	16	11	0.04	0.07	0.04	0.06	0.04	0.06
Rio Grande below Cochiti Dam, NM	4/26/17	1061926.2	353704.8	12.7	1.2	7.9	5.66	86.2	26.9	4.57	10.4	1.98	31.7	3.19	70.8	34	21	39	24	12	8	0.04	0.06	0.03	0.05	0.10	0.15
Rio Grande below Cochiti Dam, NM	8/17/17	1061926.2	353704.8	--	1.4	8	3.6	75.2	23.6	3.87	9.81	1.76	31.4	4.3	98.4	23	14	27	16	10	7	0.06	0.10	0.05	0.08	0.14	0.20
Rio Grande below Cochiti Dam, NM	1/24/18	1061926.2	353704.8	3.1	0.66	7.8	2.1	114	35.5	6	17.6	2.59	36.1	5.79	104	12	7	13	8	15	10	0.06	0.09	0.05	0.08	0.04	0.07
Rio Grande below Cochiti Dam, NM	4/12/18	1061926.2	353704.8	10.7	0.55	8	1.97	116	35.6	6.37	18.6	2.81	36.2	6.24	107	14	9	15	9	15	10	0.04	0.06	0.04	0.06	0.04	0.05
Rio Grande below Cochiti Dam, NM	8/20/18	1061926.2	353704.8	22.4	0.99	7.9	3.11	130	41.1	6.57	14.8	2.66	55.7	3.73	101	22	14	21	13	17	11	0.04	0.07	0.05	0.08	0.06	0.09
Rio Grande below Cochiti Dam, NM	2/26/19	1061926.2	353704.8	4	1.1	7.7	1.8	129	39.4	7.22	20.2	2.7	50.4	7.22	112	9	6	10	6	17	11	0.12	0.19	0.11	0.18	0.06	0.10
Rio Grande below Cochiti Dam, NM	5/21/19	1061926.2	353704.8	11.5	3.7	8.2	5.4	75.5	23.8	3.84	7.96	1.94	20.9	2.77	65.4	41	26	49	30	10	7	0.09	0.14	0.08	0.12	0.36	0.53
Rio Grande below Cochiti Dam, NM	8/19/19	1061926.2	353704.8	22.3	1.1	7.9	2.98	76	24.2	3.71	9.05	2.13	18.9	2.69	73.5	20	12	20	12	10	7	0.06	0.09	0.06	0.09	0.11	0.16
Rio Grande below Cochiti Dam, NM	1/13/20	1061926.2	353704.8	2.6	0.68	7.9	2.11	107	33.2	5.86	16	2.37	37.5	6	102	13	8	14	9	14	9	0.05	0.09	0.05	0.08	0.05	0.07
Rio Grande below Cochiti Dam, NM	5/11/20	1061926.2	353704.8	15.1	0.85	8	2.73	107	33.2	5.87	15.6	2.39	37.8	5.98	100	19	12	21	13	14	9	0.04	0.07	0.04	0.07	0.06	0.09
Rio Grande below Cochiti Dam, NM	8/17/20	1061926.2	353704.8	23	0.9	8.1	3.02	130	40.7	6.92	16.5	2.57	60.7	4.44	100	28	17	25	16	17	11	0.03	0.05	0.04	0.06	0.05	0.08
Rio Grande below Cochiti Dam, NM	1/7/21	1061926.2	353704.8	3.1	0.72	8.3	2.02	124	38.2	6.77	20	2.56	48	7.22	115	17	11	20	12	16	11	0.04	0.07	0.04	0.06	0.04	0.07
Rio Grande below Cochiti Dam, NM	5/3/21	1061926.2	353704.8	13.1	1.5	7.8	2.67	115	35.2	6.56	16.6	2.3	55	5.81	102	15	9	16	10	15	10	0.10	0.16	0.09	0.15	0.10	0.15
Rio Grande below Cochiti Dam, NM	8/9/21	1061926.2	353704.8	22.9	0.97	7.7	3.69	114	36.2	5.72	15.1	2.81	40.7	4.81	103	21	13	20	12	15	10	0.05	0.08	0.05	0.08	0.06	0.10
Rio Grande at San Felipe, NM	12/7/05	1062623.4	352640.5	3.5	1.1	8.5	1.69	123	39.4	6.1	17.2	2.68	33.6	5.57	223	16	10	20	12	17	11	0.07	0.11	0.06	0.09	0.06	0.10
Rio Grande at San Felipe, NM	12/7/05	1062623.4	352640.5	3.5	1.1	8.5	1.94	115	36.6	5.69	16.1	2.48	33.6	5.57	223	18	11	23	14	16	10	0.06	0.10	0.05	0.08	0.07	0.11
Rio Grande at San Felipe, NM	4/24/06	1062623.4	352640.5	11	1.5	8.3	1.34	114	35.3	6.27	18.3	2.61	36.4	5.92	223	12	8	13	8.1	16	10	0.12	0.20	0.12	0.19	0.09	0.15
Rio Grande at San Felipe, NM	8/14/06	1062623.4	352640.5	22.5	1.3	8.5	3.2	105	34.2	4.91	16.4	3.14	36.6	4.82	217	42	26	37	23	15	9.8	0.03	0.05	0.04	0.06	0.09	0.13

Location ID	Date	X	Y	Temp. (C)	Copper (µg/L)	pH	DOC (mg/L)	Hardness (mg/L CaCO3)	Ca	Mg	Na	K	Sulfate	Cl	Alkalinity (mg/L CaCO3)	BLM (ug/L)		MLR SSWQC (ug/L)		New Mexico Hardness-based Criteria (ug/L)		BLM		MLR SSWQC		New Mexico Hardness-based Criteria	
									(mg/L)							Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute TU	Chronic TU	Acute TU	Chronic TU	Acute TU	Chronic TU
Rio Grande at San Felipe, NM	12/4/06	1062623.4	352640.5	3.5	0.82	8.3	1.37	104	32.6	5.54	16.3	2.52	33.2	4.79	198	11	7	13	8.3	15	9.7	0.07	0.12	0.06	0.10	0.05	0.08
Rio Grande at San Felipe, NM	5/3/07	1062623.4	352640.5	13	2.2	8.2	5.49	94.8	29.4	5.2	16.6	2.53	42.6	5.96	195	45	28	50	31	13	8.9	0.05	0.08	0.04	0.07	0.17	0.25
Rio Grande at San Felipe, NM	8/22/07	1062623.4	352640.5	21.5	1.2	8.2	6.63	118	37.2	6.2	18.8	3.07	43.6	4.93	222	65	40	62	38	16	11	0.02	0.03	0.02	0.03	0.08	0.11
Rio Grande at San Felipe, NM	11/12/08	1062623.4	352640.5	8	4.8	8.3	2.54	132	41.7	6.76	20	2.83	39.7	6.24	255	22	14	25	16	18	12	0.22	0.35	0.19	0.30	0.27	0.40
Rio Grande at Alameda Bridge at Alameda, NM	12/12/05	1063834	351151.8	2.5	1.5	8.3	1.58	140	44.9	6.81	25.3	3.28	44.1	11.6	255	14	8	16	9.7	19	12	0.11	0.18	0.09	0.15	0.08	0.13
Rio Grande at Alameda Bridge at Alameda, NM	4/25/06	1063834	351151.8	16	1.5	8.6	2.16	112	35.1	6.05	20	2.94	38.8	7.37	215	27	17	27	17	16	10	0.06	0.09	0.06	0.09	0.09	0.15
Rio Grande at Alameda Bridge at Alameda, NM	8/15/06	1063834	351151.8	22	1.6	8	2.97	360	126	11.1	83.2	7.47	398	44.7	194	31	19	24	15	47	28	0.05	0.08	0.07	0.11	0.03	0.06
Rio Grande at Alameda Bridge at Alameda, NM	12/5/06	1063834	351151.8	3	0.77	8.6	1.11	110	34.7	5.74	21.9	2.88	38.1	9.68	208	11	7	14	8.4	15	10	0.07	0.11	0.06	0.09	0.05	0.08
Rio Grande at Alameda Bridge at Alameda, NM	5/4/07	1063834	351151.8	14	1.6	8.1	4.35	98.7	31.3	5.01	24.6	3.18	45.9	11.8	193	35	22	36	22	14	9.2	0.05	0.07	0.04	0.07	0.11	0.17
Rio Grande at Alameda Bridge at Alameda, NM	8/23/07	1063834	351151.8	21	1.8	7.9	7.13	119	37.5	6.25	19.2	3.06	44.4	5.32	221	50	31	50	30	17	11	0.04	0.06	0.04	0.06	0.11	0.16
Rio Grande at Alameda Bridge at Alameda, NM	11/13/08	1063834	351151.8	7.5	1.9	8.4	2.44	138	44.1	6.98	26.7	3.49	44.9	12.9	273	24	15	27	16	19	12	0.08	0.13	0.07	0.12	0.10	0.16
Rio Grande at Alameda Bridge at Alameda, NM	5/20/09	1063834	351151.8	16	1.2	8.1	6.77	91.2	29.2	4.47	10.4	2.36	29.6	3.38	154	52	32	57	35	13	8.6	0.02	0.04	0.02	0.03	0.09	0.14
Rio Grande at Alameda Bridge at Alameda, NM	8/21/09	1063834	351151.8	24.5	0.85	8.6	3.04	119	38	5.81	17.1	2.79	45.4	5.18	202	47	29	38	23	16	11	0.02	0.03	0.02	0.04	0.05	0.08
Rio Grande at Alameda Bridge at Alameda, NM	11/23/09	1063834	351151.8	8.6	1	8.4	2.37	132	42.1	6.59	22.9	3.03	45.7	9.32	254	23	14	26	16	18	12	0.04	0.07	0.04	0.06	0.06	0.08
Rio Grande at Alameda Bridge at Alameda, NM	5/11/10	1063834	351151.8	13.6	0.87	8.2	4.7	94.5	30.3	4.59	13.7	2.26	33.9	5.42	172	39	24	43	26	13	8.9	0.02	0.04	0.02	0.03	0.07	0.10
Rio Grande at Alameda Bridge at Alameda, NM	8/17/10	1063834	351151.8	25.6	1.2	8.1	4.03	113	36	5.52	18.4	3.29	47.3	7.84	201	38	24	34	21	16	10	0.03	0.05	0.04	0.06	0.08	0.12
Rio Grande at Alameda Bridge at Alameda, NM	12/3/10	1063834	351151.8	5.9	0.5	8.4	1.96	138	43.7	7.12	26.9	3.46	47.8	12.7	258	19	12	21	13	19	12	0.03	0.04	0.02	0.04	0.03	0.04
Rio Grande at Alameda Bridge at Alameda, NM	6/3/11	1063834	351151.8	16.9	0.71	8.2	3.38	122	38.2	6.59	17.1	2.7	47.3	5.32	210	30	19	31	19	17	11	0.02	0.04	0.02	0.04	0.04	0.06
Rio Grande at Alameda Bridge at Alameda, NM	8/18/11	1063834	351151.8	27.9	0.81	8.1	3.86	104	32.3	5.57	14	2.99	37	3.86	186	37	23	32	20	14	9.6	0.02	0.03	0.03	0.04	0.06	0.08

Location ID	Date	X	Y	Temp. (C)	Copper (µg/L)	pH	DOC (mg/L)	Hardness (mg/L CaCO3)	Ca	Mg	Na	K	Sulfate	Cl	Alkalinity (mg/L CaCO3)	BLM (ug/L)		MLR SSWQC (ug/L)		New Mexico Hardness-based Criteria (ug/L)		BLM		MLR SSWQC		New Mexico Hardness-based Criteria	
									(mg/L)							Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute TU	Chronic TU	Acute TU	Chronic TU	Acute TU	Chronic TU
Rio Grande at Alameda Bridge at Alameda, NM	12/9/11	1063834	351151.8	3.2	0.8	8.1	2.53	119	37.2	6.29	17.8	2.89	35.8	6.49	223	18	11	21	13	16	11	0.04	0.07	0.04	0.06	0.05	0.07
Rio Grande at Alameda Bridge at Alameda, NM	4/26/12	1063834	351151.8	16	0.92	8.3	3.83	95.7	29.9	5.13	17.9	2.68	29.7	9.18	184	37	23	38	23	13	9	0.03	0.04	0.02	0.04	0.07	0.10
Rio Grande at Alameda Bridge at Alameda, NM	8/23/12	1063834	351151.8	23.5	1	8.2	4	131	42.1	6.54	17.5	3.75	43.3	4.82	226	41	26	37	23	18	12	0.02	0.04	0.03	0.04	0.06	0.08
Rio Grande at Alameda Bridge at Alameda, NM	12/20/12	1063834	351151.8	1.2	0.8	8.2	2.58	137	43.3	7.12	20.3	2.83	49.8	6.45	240	20	12	24	15	19	12	0.04	0.07	0.03	0.05	0.04	0.07
Rio Grande at Alameda Bridge at Alameda, NM	5/10/13	1063834	351151.8	16.3	0.8	8.1	2.35	124	38.1	7	21.3	2.87	54.5	6.1	231	20	12	20	12	17	11	0.04	0.07	0.04	0.07	0.05	0.07
Rio Grande at Alameda Bridge at Alameda, NM	8/2/13	1063834	351151.8	23.2	0.84	8.1	4.52	141	45.3	6.81	22.3	4.26	55.9	6.24	255	43	27	38	24	19	13	0.02	0.03	0.02	0.04	0.04	0.06
Rio Grande at Alameda Bridge at Alameda, NM	12/18/13	1063834	351151.8	4	1.8	8.2	2.77	135	42.5	7.07	26	3.44	49.9	12.1	252	22	14	25	16	19	12	0.08	0.13	0.07	0.11	0.09	0.15
Rio Grande at Alameda Bridge at Alameda, NM	5/13/14	1063834	351151.8	11.9	0.8	8.2	2.97	127	40.1	6.59	21.6	3.02	58.7	7.59	220	25	16	27	17	18	11	0.03	0.05	0.03	0.05	0.04	0.07
Rio Grande at Alameda Bridge at Alameda, NM	8/22/14	1063834	351151.8	21.4	1.2	8.2	3.21	123	39.9	5.71	17.8	3.76	40.7	22.6	220	32	20	29	18	17	11	0.04	0.06	0.04	0.07	0.07	0.11
Rio Grande at Alameda Bridge at Alameda, NM	1/7/15	1063834	351151.8	5.6	0.8	8.1	2.06	122	38.1	6.54	26	3.28	49.4	14.6	243	15	10	17	11	17	11	0.05	0.08	0.05	0.07	0.05	0.07
Rio Grande at Alameda Bridge at Alameda, NM	3/28/15	1063834	351151.8	12.8	1.6	7.5	3.53	98.6	30.9	5.23	20.7	3.06	32.5	10.4	212	15	9	15	9.3	14	9.2	0.11	0.18	0.11	0.17	0.11	0.17
Rio Grande at Alameda Bridge at Alameda, NM	5/26/16	1063834	351151.8	17.1	0.98	8	4.35	105	32.8	5.56	15.8	2.67	36.7	5.37	90.1	32	20	33	20	14	9	0.03	0.05	0.03	0.05	0.07	0.10
Rio Grande at Alameda Bridge at Alameda, NM	8/30/16	1063834	351151.8	23.8	1.9	8	2.98	114	37.5	4.8	17	2.88	50.7	6.09	98.4	24	15	23	14	15	10	0.08	0.13	0.08	0.14	0.12	0.19
Rio Grande at Alameda Bridge at Alameda, NM	12/14/16	1063834	351151.8	7.3	0.89	8.4	1.91	132	41.4	6.94	23	3.05	48.7	9.25	120	18	11	21	13	17	11	0.05	0.08	0.04	0.07	0.05	0.08
Rio Grande at Alameda Bridge at Alameda, NM	4/28/17	1063834	351151.8	11.6	1.2	7.9	4.84	90.8	28.5	4.71	12.6	2.12	33.9	5.07	77.9	29	18	33	20	12	8	0.04	0.07	0.04	0.06	0.10	0.15
Rio Grande at Alameda Bridge at Alameda, NM	8/18/17	1063834	351151.8	23.1	1.1	8.2	3.31	107	33.8	5.35	16.1	2.79	34.1	6.56	103	33	20	30	19	14	9	0.03	0.05	0.04	0.06	0.08	0.12
Rio Grande at Alameda Bridge at Alameda, NM	1/25/18	1063834	351151.8	1.7	0.59	8	1.98	126	39.8	6.39	27.5	3.11	45.5	15.2	118	14	9	15	9	17	11	0.04	0.07	0.04	0.06	0.04	0.05
Rio Grande at Alameda Bridge at Alameda, NM	4/13/18	1063834	351151.8	9.6	0.56	8.2	1.72	120	37.6	6.37	23	3.33	39.5	9.12	115	15	9	16	10	16	10	0.04	0.06	0.04	0.06	0.04	0.05

Location ID	Date	X	Y	Temp. (C)	Copper (µg/L)	pH	DOC (mg/L)	Hardness (mg/L CaCO3)	Ca	Mg	Na	K	Sulfate	Cl	Alkalinity (mg/L CaCO3)	BLM (ug/L)		MLR SSWQC (ug/L)		New Mexico Hardness-based Criteria (ug/L)		BLM		MLR SSWQC		New Mexico Hardness-based Criteria	
									(mg/L)							Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute TU	Chronic TU	Acute TU	Chronic TU	Acute TU	Chronic TU
Rio Grande at Alameda Bridge at Alameda, NM	8/22/18	1063834	351151.8	22.9	1.1	7.9	3.1	118	37.7	5.71	14.9	2.6	54.9	4.69	103	22	14	21	13	16	10	0.05	0.08	0.05	0.08	0.07	0.11
Rio Grande at Alameda Bridge at Alameda, NM	2/28/19	1063834	351151.8	7.5	1.3	8.1	1.78	113	35.1	6.18	20.9	2.66	52.3	11.3	119	13	8	15	9	15	10	0.10	0.16	0.09	0.14	0.09	0.13
Rio Grande at Alameda Bridge at Alameda, NM	8/21/19	1063834	351151.8	22.3	0.92	8.3	2.82	82.5	26.2	4.06	10.6	2.46	21.2	3.39	79.6	29	18	28	17	11	8	0.03	0.05	0.03	0.05	0.08	0.12
Rio Grande at Alameda Bridge at Alameda, NM	1/15/20	1063834	351151.8	3.7	1.1	8.5	2.12	120	37.7	6.23	21.5	2.72	43.9	11.6	115	20	13	25	15	16	10	0.05	0.09	0.04	0.07	0.07	0.11
Rio Grande at Alameda Bridge at Alameda, NM	8/19/20	1063834	351151.8	23.9	2.8	8.5	3.1	136	42.9	6.94	20.3	3.07	61.3	7.23	108	44	27	37	22	18	12	0.06	0.10	0.08	0.12	0.16	0.24
Rio Grande at Alameda Bridge at Alameda, NM	1/11/21	1063834	351151.8	3.7	0.62	8.4	2.01	138	43.1	7.35	23.7	3.02	54.3	9.44	127	19	12	22	13	18	12	0.03	0.05	0.03	0.05	0.03	0.05
Rio Grande at Alameda Bridge at Alameda, NM	5/5/21	1063834	351151.8	14.3	0.91	8.3	2.82	122	37.4	6.73	20.3	2.67	56.3	8.61	106	27	17	28	17	16	11	0.03	0.05	0.03	0.05	0.06	0.09
Rio Grande at Alameda Bridge at Alameda, NM	8/11/21	1063834	351151.8	23.1	0.81	8.2	3.28	123	39.4	5.87	18.6	3.2	43.7	7.15	112	33	21	30	19	16	11	0.02	0.04	0.03	0.04	0.05	0.08

BLM – biotic ligand model
DOC – dissolved organic carbon
ID – identification
MLR – multiple linear regression
SSWQC – site-specific water quality criteria
TU – toxic unit
WQC – water quality criteria

D3 Rio Grande Silvery Minnow (*Hybognathus amarus*)

The Rio Grande silvery minnow (family *Cyprinidae*) is a small schooling fish species that lives in a restricted range of the Rio Grande in New Mexico between Cochiti Pueblo and Elephant Butte Reservoir. Historically, the range this species was larger; it has been fragmented by dams and degraded by various hydrologic modifications (USFWS 2021). Silvery minnow prefer large, warm, riverine habitat with low to moderate flows over relatively fine substrates. They are benthic feeders, consuming plant material and benthic invertebrates at the sediment-water interface.

As with the Rio Grande cutthroat trout, discussed above, adverse effects on minnow are not expected as a result of the proposed copper SSWQC. Adopting and implementing these criteria would provide a suitable level of protection for sensitive aquatic life (including minnow prey), and historical copper concentrations have not exceeded the proposed SSWQC (Table D-1). The EPA (2007) dataset contains toxicity data for other cyprinids that are less sensitive than salmonids (discussed above) and substantially less sensitive than aquatic invertebrates included in that dataset.

D4 New Mexico Jumping Mouse (*Zapus hudsonius luteus*)

The range of the New Mexico jumping mouse (*Zapus hudsonius luteus*) includes the Jemez, Sangre de Cristo, San Juan, White, and Sacramento Mountains of New Mexico, Arizona, and Colorado as well as riparian areas along the main stem of Rio Grande (USFWS 2020). This species generally inhabits elevations below 9,500 feet and is typically observed within close proximity to perennial streams. The jumping mouse hibernates from September or October to May or June with a limited active period. They are mainly active in summer months when riparian forb, sedge, and grass seeds are plentiful. Therefore, upon emergence from hibernation, jumping mice must breed, rear their young, and then accumulate sufficient fat reserves to sustain them through the next hibernation period all within a few months. While little research is available on jumping mouse hibernacula, what data are available suggest that jumping mice hibernate in small nests made of vegetation under shrubs or in underground burrows, typically close perennial water bodies.

Jumping mice primarily breed in July or August and likely only have one litter each year (USFWS 2020). Jumping mice use dense riparian herbaceous vegetation as shelter and food source, however females use areas outside the moist riparsian zone for giving birth and rearing young. Jumping mice most likely only have a life span of one to two years and are prey for snakes, foxes, weasels, and birds of prey.

It is not expected that the SSWQC would adversely impact the New Mexico jumping mouse. Jumping mice feed primarily on terrestrial plant matter and to a lesser extent on invertebrates (e.g., insects and snails) and fruit (USFWS 2020), and these dietary items would not be adversely impacted by a change in the copper WQC. Copper concentrations associated with the SSWQC are protective of fish and small aquatic invertebrate species; the potential for impacts in a larger mammalian species that is exposed to a far lesser degree (i.e., through water ingestion or dermal exposures), is expected to be very low.

D5 Mexican Spotted Owl (*Strix occidentalis lucida*)

The Mexican spotted owl occupies a broad geographic range which extends north from Aguascalientes, Mexico, throughout Arizona, New Mexico, Utah, Colorado, and into western Texas (Palumbo and Johnson 2015). The owl commonly occupies mixed-conifer forests, and the highest densities of owl occur in forests that have minimal human disturbance. Home ranges for Mexican spotted owl vary from about 260 to 1,500 hectares.

Mexican spotted owl consume a variety of terrestrial prey including small and medium sized rodents (e.g., woodrats, mice, and voles), bats, birds, and reptiles. Nesting habitats are in areas with complex forest structure or rocky canyons that contain mature or old growth conifer forests (Palumbo and Johnson 2015). Some Mexican spotted owls are year-round residents within an area and some move considerable distances, generally to more open habitat at lower elevations during the winter (Palumbo and Johnson 2010).

It is not expected that the Mexican spotted owl would be adversely affected by a change in copper WQC consistent with EPA's national recommended copper AWQC for aquatic life. They prey on small terrestrial mammals, birds, and reptiles rather than aquatic life. Exposures of owls to dissolved copper would be very limited; owls tend not to drink water (instead getting water through their diet) but may be dermally exposed periodically while bathing. Considering the relatively low potential (including frequency and duration) for exposure, the low potential for copper toxicity through a dermal route of exposure (and lack of a route through ingestion), and the relative insensitivity of large birds to copper exposures at what should be an acceptable level for small, sensitive aquatic life, it is concluded that Mexican spotted owl will not be affected by a change in the copper WQC.

D6 Southwestern Willow Flycatcher (*Empidonax traillii extimus*)

The southwestern willow flycatcher has a broad range across the southwest including California, Arizona, New Mexico, Colorado, Utah, and Nevada (Sogge et al. 2010). They breed in North America, but winter in the subtropical and tropical regions of southern Mexico, Central America, and northern South America. Breeding and nesting habitat is dense riparian vegetation (with tree and shrub cover) where there is surface water present or where soil moisture is high enough to maintain dense vegetation. Flycatcher habitat selection appears to be driven more by plant structure than by species composition; nests are placed where there is suitable twig and vegetative structure.

Flycatchers are insectivores and prey upon a variety of taxa including leafhoppers (Homoptera), dragonflies (Odonata), true bugs (Hemiptera), bees and wasps (Hymenoptera), and flies (Diptera) (Sogge et al. 2010). Flycatcher's diet may include species with an aquatic larval life stage. The copper BLM (and, by extension, the SSWQC) is not expected to adversely impact flycatcher dietary items; rather, the BLM is intended to be protective of aquatic life and should therefore be protective of flycatcher prey.

Flycatchers may directly ingest dissolved copper while drinking or bathing. As noted above, birds are less sensitive to copper than is aquatic life, so the copper BLM (and, by extension, the SSWQC) should also be protective of birds exposed dermally or through drinking and protective of potential prey bases for birds.

D7 Yellow-billed Cuckoo (*Coccyzus americanus*)

Historically, the yellow-billed cuckoo bred throughout most of continental North America, but currently it is only found in the southwest, Midwest, and eastern US and Canada (Wiggins 2005). Yellow-billed cuckoos winter in South America, mostly east of the Andes Mountains, only spending late spring and summer months in North America. In southwest regions cuckoos prefer to nest in riparian woodlands, particularly those with an intact understory. Nests are made in dense patches of broad-leaved deciduous trees close to water.

Yellow-billed cuckoos feed on insects including grasshoppers, crickets, and katydids (Orthoptera), caterpillars (Lepidoptera), true bugs (Hemiptera), and beetles (Coleoptera). Prey types change seasonally based on availability. However, because the BLM and SSWQC are intended to be protective of aquatic life, it is unlikely that cuckoo's prey would be adversely affected by copper exposures below the criteria.

D8 Jemez Mountains Salamander (*Plethodon neomexicanus*)

The Jemez Mountains Salamander is restricted to coniferous forests at elevations between approximately 7,000 and 11,000 ft in north-central New Mexico (78 FR 69569), including the Jemez Mountains in Los Alamos, Rio Arriba, and Sandoval Counties and around Valles Caldera National Preserve (primarily along the rim of the collapsed caldera with some occurring within the caldera) (Ramotik and Scott 1988).

The Jemez Mountains salamander is strictly terrestrial and does not use standing water for any life stage (78 FR 55600). They spend much of their life underground but emerge when conditions are warm and wet, typically from July through September. Aboveground activity usually occurs under decaying logs, rocks, bark, or moss mats. Salamanders prey on ants (e.g., Hymenoptera and Formicidae), mites (Acari), and beetles (Coleoptera). While reproduction in the wild has not been observed, based on the laboratory setting, mating is believed to occur between July and August during the summer monsoon season. Eggs are thought to be laid underground, and fully formed salamanders hatch from the eggs; there is no tadpole life stage that would be subject to waterborne exposure.

Because they are limited to terrestrial habitat and prey, the use of the SSWQC is not expected to adversely affect the Jemez Mountain salamander directly or indirectly (through diet or habitat alteration). It is assumed that Jemez Mountain salamander, like other salamander species, absorb moisture from their environment rather than drinking water from streams; therefore, this species would not be exposed to dissolved copper levels related to the SSWQC.

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EXHIBIT E

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Refer To: N3B-2024-0021

Communities for Clean Water
c/o Rachel Conn
Amigos Bravos
P.O. Box 238
Taos, NM 87571

Subject: Enclosed is the Updated Copper Site-Specific Water Quality Criteria for the Pajarito Plateau: Demonstration Report, Dated November 20, 2023, and the Response to the Communities for Clean Water Comments on N3B's Draft Copper Criteria for the Pajarito Plateau Report, Dated November 9, 2023

Dear Communities for Clean Water:

On November 9, 2023, the U.S. Department of Energy Environmental Management Los Alamos Field Office (EM-LA) and Newport News Nuclear BWXT-Los Alamos, LLC (N3B) received comments from the Communities for Clean Water (CCW) on the "Copper Site-Specific Water Quality Criteria for the Pajarito Plateau: Demonstration Report" (hereafter, Demonstration Report).

On September 26, 2023, EM-LA and N3B held a public meeting to discuss the Demonstration Report. A public comment period was open from September 25 to November 9, 2023. On November 9, 2023, CCW provided comments and requested a digital copy of Appendix A. EM-LA/N3B appreciate CCW's review and comments on the Demonstration Report, and are pleased to provide the complete Demonstration Report, including Appendix A on CD (Enclosure 1) and the response to CCW's comments (Enclosure 2).

If you have questions, please contact Amanda White at (505) 309-1366 (amanda.white@em-la.doe.gov) or Cheryl Rodriguez at (505) 414-0450 (cheryl.rodriguez@em.doe.gov).

Sincerely,

Troy Thomson
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Sincerely,

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Arturo Q. Duran
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Office of Quality and Regulatory Compliance
U.S. Department of Energy
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Los Alamos Field Office

Enclosure(s):

1. Copper Site-Specific Water Quality Criteria for the Pajarito Plateau: Demonstration Report, Dated November 20, 2023 (including a redline strikeout version)
2. Response to Comments on N3B's Draft Copper Criteria for the Pajarito Plateau Report, Provided by Communities For Clean Water, Dated November 9, 2023

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ENCLOSURE 1

Copper Site-Specific Water Quality Criteria for the Pajarito Plateau: Demonstration Report

COPPER SITE-SPECIFIC WATER QUALITY CRITERIA FOR THE PAJARITO PLATEAU: DEMONSTRATION REPORT

Prepared for

Newport News Nuclear BWXT Los Alamos
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November 20, 2023

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Acronyms

%HA	percent humic acid
AIC	Akaike's Information Criterion
APS	automated pump samplers
AU	Assessment Unit
BIC	Bayesian Information Criterion
BLM	biotic ligand model
BTV	background threshold value
CCC	Criterion Continuous Concentration
CFR	Code of Federal Regulations
CMC	Criterion Maximum Concentration
COC	chain of custody
CWA	Clean Water Act
DOC	dissolved organic carbon
DOE	US Department of Energy
DQA	data quality assessment
DQO	data quality objective
EIM	Environmental Information Management
EPA	US Environmental Protection Agency
ESA	Endangered Species Act
ID	identification
IP	Individual Permit
IPAC	Information for Planning and Consultation
IR	integrated report
LAC	Los Alamos County
LANL	Los Alamos National Laboratory
LOP	level of protection
MLR	multiple linear regression
MSGP	Multi-Sector General Permit
N3B	Newport News Nuclear BWXT Los Alamos
NMAC	New Mexico Administrative Code

NMED	New Mexico Environment Department
NPDES	National Pollutant Discharge Elimination System
ONRW	Outstanding National Resource Water
QA/QC	quality assurance/quality control
SSWQC	site-specific water quality criteria
SWQB	Surface Water Quality Bureau
TAL	target action level
TMDL	total maximum daily load
TOC	total organic carbon
USGS	United States Geological Survey
WER	water-effect ratio
Windward	Windward Environmental LLC
WQC	water quality criteria
WQCC	Water Quality Control Commission
WQS	water quality standards
WWTF	wastewater treatment facility

Executive Summary

This report describes the development of site-specific water quality criteria (SSWQC) for copper in surface waters of the Pajarito Plateau, in accordance with the US Environmental Protection Agency's (EPA's) nationally recommended ambient water quality criteria and New Mexico Water Quality Standards (20.6.4 NMAC) procedures for site-specific criteria.

In 2007, EPA issued revised nationally recommended freshwater aquatic life criteria for copper based upon the biotic ligand model (BLM) (EPA 2007a). EPA recognizes the BLM as best available science for setting copper criteria, because it explicitly considers the effects of multiple water chemistry parameters beyond hardness that affect the bioavailability of copper and its toxicity to aquatic life.

The copper SSWQC were developed using a multiple linear regression (MLR) method that combined water chemistry data from Pajarito Plateau surface waters with output from the copper biotic ligand model (BLM) (EPA 2007a). The MLR-based SSWQC are simple equations that accurately predict acute or chronic copper BLM criteria output using only three water chemistry parameters, making the SSWQC simpler to use than the BLM while maintaining the scientific rigor of the BLM.

The BLM is recognized by the New Mexico Environment Department (NMED) as a more accurate method of assessing copper bioavailability than New Mexico's current hardness-based criteria (NMWQCC 2021). While New Mexico has not yet adopted EPA's ambient water quality criteria statewide because of the data needed to calculate BLM-based copper criteria, it has approved the BLM as a copper SSWQC method (20.6.4.10D(4)(c) NMAC).

Streams on the Pajarito Plateau have been extensively monitored under a variety of EPA and NMED programs over a 15-year period in order to make the Pajarito Plateau a suitable setting for developing BLM-based SSWQC. A site-specific dataset of BLM parameters was developed based on monitoring conducted from 2005 to 2019. The dataset includes a total of 531 discrete samples with sufficient water chemistry parameters to generate BLM-based criteria. Samples were collected from 50 different locations across 9 different watersheds and under a diverse set of hydrologic regimes.

Statistical evaluation of the site-specific dataset demonstrated that pH, dissolved organic carbon (DOC), and hardness account for 98% of the variation in BLM-based criteria for the Pajarito Plateau streams. The influences of other site-specific factors were considered, including hydrologic conditions (i.e., ephemeral, intermittent, or perennial regime), land use (i.e., developed or undeveloped areas), a major forest fire in 2011, and the use of different methods for predicting DOC from total organic carbon (TOC). The statistical evaluation showed that the copper BLM can be simplified, using the MLR method, into the following equations for acute Criterion Maximum Concentration (CMC) and chronic Criterion Continuous Concentration (CCC) :

$$\boldsymbol{CMC = exp(-22.914 + 1.017 \times ln(DOC) + 0.045 \times ln(hardness) + 5.176 \times pH - 0.261 \times pH^2)}$$

$$\boldsymbol{CCC = exp(-23.391 + 1.017 \times ln(DOC) + 0.045 \times ln(hardness) + 5.176 \times pH - 0.261 \times pH^2)}$$

This report demonstrates that these MLR equations accurately estimate BLM criteria over the range of water chemistries and hydrologic regimes observed on the Pajarito Plateau. Therefore, these equations can be adopted as copper SSWQC for surface waters of the Pajarito Plateau to provide criteria that are protective of aquatic life uses in accordance with EPA recommendations (i.e., accurate to the BLM).

1 Introduction

On behalf of Newport News Nuclear BWXT Los Alamos (N3B), Windward Environmental LLC (Windward) has prepared this demonstration report, which describes the development of copper site-specific water quality criteria (SSWQC) for surface waters of the Pajarito Plateau in Los Alamos County (LAC), New Mexico. This report presents and justifies the derivation of a dissolved copper SSWQC in accordance with New Mexico Water Quality Standards (WQS) (20.6.4.10 New Mexico Administrative Code [NMAC]). It also presents the methods, available data, and spatial boundaries for deriving copper SSWQC for surface waters of the Pajarito Plateau.

New Mexico's current aquatic life water quality criteria (WQC) for copper (20.6.4.900 NMAC) are based on the 1996 US Environmental Protection Agency (EPA)-recommended copper criteria (EPA 1996), which were based on an equation that considered only the effect of water hardness on copper bioavailability and toxicity. EPA periodically revises its nationally recommended WQC for aquatic life to reflect current scientific knowledge. In 2007, EPA released updated Clean Water Act (CWA) §304(a) guidance for copper WQC to reflect new knowledge and an improved understanding of the effects of multiple water chemistry parameters on copper toxicity. The EPA (2007a)-recommended copper criteria reflect the "best available science" and significant advancements in scientific understanding of metal speciation, bioavailability, and toxicity.

Per EPA's recommendation, the biotic ligand model (BLM) incorporates these advancements and can be used to generate aquatic life WQC based on local water chemistry. The BLM builds on the old hardness-based criteria by incorporating additional water chemistry parameters that affect copper speciation, bioavailability, and toxicity. The current version of the copper BLM software is available through EPA (https://www.epa.gov/wqc/aquatic-life-criteria-copper).

The statistical model-based approach described in this report for developing copper SSWQC for surface waters of the Pajarito Plateau stems from EPA (2007a) recommendations for using the copper BLM and New Mexico WQS procedures to develop copper SSWQC. The physical and chemical characteristics (i.e., BLM parameters) of Pajarito Plateau surface waters have been rigorously monitored at a variety of locations, so it is a suitable setting to develop copper SSWQC. The proposed SSWQC—multiple linear regression (MLR) equations that accurately predict BLM outputs using a subset of the BLM inputs—are intended for eventual use in all National Pollutant Discharge Elimination System (NPDES) permits and by New Mexico Environment Department (NMED) for CWA §303(d)/305(b) Integrated Assessments.

1.1 RATIONALE AND METHODS

Copper is an abundant trace element that occurs naturally in the earth's crust, and an essential micronutrient required by virtually all plants and animals. At elevated concentrations, copper can have adverse effects on some forms of aquatic life, but such effects depend on site-specific chemistry. Both natural and anthropogenic sources introduce copper to Pajarito Plateau surface waters (Los Alamos National Laboratory [LANL] 2013; Windward 2020).

To protect aquatic life uses from copper toxicity, New Mexico's WQS establish the following state-wide dissolved copper criteria based on EPA's outdated 1996 ambient water quality criteria document (EPA 1996):

Acute criterion (µg/L) = exp(0.9422 × ln(hardness) – 1.700) × 0.96

Chronic criterion (µg/L) = exp(0.8545 × ln(hardness) – 1.702) × 0.96

As described by EPA (2018c), these hardness-based copper criteria were developed from an empirical relationship between toxicity and water hardness. Their development did not explicitly consider the effects of other water chemistry parameters that markedly affect copper bioavailability and toxicity.

In February 2007, EPA published *Aquatic Life Ambient Freshwater Quality Criteria – Copper* to address water chemistry parameters beyond hardness, and to reflect the latest scientific knowledge on copper bioavailability and toxicity (EPA 2007a). The criteria 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 scientific information, supplementing EPA's previously published recommendation 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 concentration of copper that will be protective of aquatic life." By using the BLM to develop MLRs, this demonstration report relies on the most recent available scientific information and EPA's current recommendations to develop copper SSWQC.

EPA's regulation at 40 Code of Federal Regulations (CFR) 131.11(b)(1)(ii) provides that states and tribes may adopt WQC that have been modified to reflect site-specific conditions. New Mexico WQS describe conditions under which SSWQC may be developed, including "physical or chemical characteristics at a site such as pH or hardness alter the biological availability and/or toxicity of the chemical" (20.6.4.10.D(1) NMAC). Consistent with EPA regulations, New Mexico WQS require a scientifically defensible method to derive SSWQC. The WQCC explicitly recognizes "the biotic ligand model as described in aquatic life ambient freshwater quality criteria – copper" (EPA 2007a) as one such scientifically defensible method to derive SSWQC (20.6.4.10.D(4) NMAC).

In addition, 40 CFR 131.20(a) requires that States adopt EPA Section 304(a) criteria or provide an explanation if not adopted when the results of the Triennial Review are submitted consistent with CWA section 303(c). As part of New Mexico's 2020 Triennial Review, EPA recommended that New Mexico update its aquatic life criteria for copper to reflect the latest science contained in the 304(a) copper criteria (EPA 2020). NMED stated in direct testimony that the BLM provides a more accurate assessment of copper bioavailability than New Mexico's hardness-based criteria calculation, but noted that it requires multiple water quality parameters (some of which are not commonly available) as a potential limitation of the copper BLM, and therefore, recommended that the WQCC not adopt the criteria state-wide. The limitation described in the 2020 Triennial Review is not an issue for the current proposal because BLM parameters have been sampled in Pajarito Plateau surface waters since 2005. Furthermore, the proposed copper SSWQC equations use only a subset of the BLM input parameters.

The EPA (2007a) copper BLM explicitly and quantitatively accounts for how individual water quality parameters affect the bioavailability and toxicity of copper to aquatic organisms. The BLM software relies on 12 water chemistry parameters as inputs to generate BLM-based WQC, but most parameters have little or no effect on the speciation, bioavailability, and toxicity of copper and, thus, on the magnitude of any resulting BLM-based WQC.[1]

To provide a more streamlined and transparent approach for adopting and implementing copper SSWQC for the Pajarito Plateau, BLM-based WQC were simplified into three-parameter acute and chronic equations using an MLR method. This approach is consistent with EPA's approach for setting WQC for other chemicals,[2] as well as with approaches described in the scientific literature for developing copper WQC (e.g., Brix et al. 2017) and EPA-approved approaches for simplifying the copper BLM into an MLR equation for SSWQC (EPA 2016a).

The proposed copper SSWQC equations were developed based on statistical analyses of BLM parameters monitored in Pajarito Plateau streams from 2005 to 2019. Three parameters (pH, dissolved organic carbon [DOC], and hardness) were found to have a significant impact on BLM-based criteria for the site-specific dataset. The SSWQC equations build upon New Mexico's current hardness-based equations to incorporate the combined effects of pH, hardness, and DOC. The evaluations presented in this report demonstrate how the proposed SSWQC equations accurately

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[1] The BLM can also be used to evaluate the site-specific speciation, bioavailability, and toxicity of copper and several other metals. The sensitivity of the BLM's output to a given water chemistry parameter varies among different metals. When the BLM is being used to develop WQC for a single metal—in this case, copper—the model can be simplified to include only the sensitive parameters for that metal as model variables.

[2] For example, EPA-recommended aquatic life criteria for aluminum and ammonia are based on MLR equations that use multiple water quality parameters to generate criteria (EPA 2013, 2018b).

estimate EPA (2007a) BLM-based copper criteria over the range of water chemistries and hydrologic regimes of the Pajarito Plateau.

1.2 REPORT CONTENTS

The remaining report is organized into the following sections:

- Regulatory background for establishing SSWQC (Section 2)
- Background on the physical setting, New Mexico WQS, permitted discharges, and monitoring programs (Section 3)
- Overview of scientific methods and regulatory processes for deriving SSWQC (Section 4)
- Summary of available surface water data and methods for deriving copper SSWQC (Section 5)
- Recommended copper SSWQC for surface waters of the Pajarito Plateau (Section 6)
- References cited (Section 7)

Additionally, there are four appendices to this report:

- Appendix A is a table of the data used to develop SSWQC.
- Appendix B provides additional details on the SSWQC development methods and results.
- Appendix C is the Public Involvement Plan (also see Section 2.1.5).
- Appendix D is an evaluation of threatened and endangered species (also see Section 2.5).

2 Regulatory Background

This section provides the regulatory background and framework for developing SSWQC in accordance with EPA guidance and New Mexico's WQS.

2.1 Regulatory Framework for Developing SSWQC

EPA's regulation at 40 CFR 131.11(b)(1)(ii) provides that states and tribes may adopt WQC that are "modified to reflect site-specific conditions." As with all criteria, SSWQC must be based on sound scientific rationale, protect designated uses, and are subject to EPA review and approval or disapproval under §303(c) of the CWA (EPA 2007a).

New Mexico's WQS (20.6.4.10.D NMAC) specify the following requirements for adopting SSWQC for New Mexico surface waters:

- Relevant site-specific conditions for developing SSWQC
- Protectiveness of SSWQC to designated uses
- Scientific methods for deriving SSWQC
- Petition and stakeholder/public review process for adopting SSWQC

Each factor is discussed in the following sections.

2.1.1 Relevant conditions for developing SSWQC

In accordance with New Mexico's WQS (20.6.4.10.D.1 NMAC), SSWQC may be adopted based on relevant site-specific conditions, such as:

- Actual species at a site are more or less sensitive than those used in the national criteria dataset.
- Physical or chemical characteristics at a site, such as pH or hardness, alter the biological availability and/or toxicity of a chemical.
- Physical, biological, or chemical factors alter the bioaccumulation potential of a chemical.
- The concentration resulting from natural background exceeds numeric criteria for aquatic life, wildlife habitat, or other uses if consistent with Subsection E of 20.6.4.10 NMAC.
- Other factors or combination of factors, upon review by Water Quality Control Commission (WQCC), may warrant modification of the default criteria, subject to EPA review and approval.

The rationale for the copper SSWQC described in this report is that water chemistry parameters beyond hardness alter the bioavailability and toxicity of copper to aquatic organisms (EPA 2007a). EPA recommends using the copper BLM to establish copper criteria, as the BLM incorporates the effects of multiple water chemistry parameters and reflects the best available scientific information.

NMED recognizes that the BLM represents the best available science for setting copper WQC (NMWQCC 2021). It recommended that within New Mexico the BLM be adopted on a site-specific basis. Because LANL has analyzed BLM parameters for a large number of surface water samples from the Pajarito Plateau (Appendices A and B), site-specific adoption of the BLM for waters of the Pajarito Plateau is appropriate and consistent with the New Mexico WQS. The proposed SSWQC are based on statistical evaluation and modeling demonstrating that pH, DOC, and hardness have a significant effect on accurately generating BLM-based copper criteria, consistent with findings that others have reported (EPA 2007a). Additional discussion of Pajarito Plateau-specific water chemistry conditions and how they influence copper criteria is provided in Section 5 (e.g., Sections 5.1, 5.3, and 5.4).

2.1.2 Protectiveness of SSWQC

In accordance with 20.6.4.10.D.2 NMAC, "site-specific criteria must fully protect the designated use to which they apply." The copper SSWQC described in this report are based on EPA (2007a) criteria for protection of aquatic life uses and will fully protect aquatic life uses on the Pajarito Plateau to the same extent as the EPA (2007a) criteria.

Relative to hardness-based copper WQC for aquatic life, EPA (2007a) reports:

> 'Stringency' likely varies depending on the specific water chemistry of the site. The 1986 hardness-based equation and resulting copper criteria reflected the effects of water chemistry factors such as hardness (and any of the other factors that were correlated with hardness, chiefly pH and alkalinity). However, the hardness based criteria, unadjusted with the WER [water effect ratio], did not explicitly consider the effects of DOC and pH, two of the more important parameters affecting copper toxicity. The application resulted in copper criteria that were potentially under-protective (i.e., not stringent enough) at low pH and potentially over-protective (i.e., too stringent) at higher DOC levels.
>
> By contrast, the BLM-based recommended criterion should more accurately yield the level of protection intended to protect and maintain aquatic life uses. By using the latest science currently available, application of the BLM-derived copper criteria should be neither under-protective nor over-protective for protection and maintenance of aquatic life uses affected by copper.

BLM-based WQC may be higher or lower than hardness-based WQC, depending on water chemistry. When the BLM-based WQC are lower, they are sometimes mistakenly referred to as "more stringent" (and vice-versa). Rather, changes in the

BLM-based WQC reflect changes in water chemistry and copper bioavailability, not changes in the stringency (i.e., level of protection [LOP]). As described by EPA (2021), BLM-based criteria will in some cases be higher and in other cases be lower than hardness-based criteria. "Although there is not a single water quality criteria value to use for comparison purposes, the BLM-based water quality criteria for copper provides an improved framework for evaluating a 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" (EPA 2021).

Thus, the copper SSWQC described in this report will fully protect aquatic life uses on the Pajarito Plateau in accordance with EPA recommendations.

As part of this evaluation, Rio Grande water chemistry data from the National Water Quality Monitoring Council's Water Quality Portal website (National Water Quality Monitoring Council 2019) were considered to ensure that the SSWQC would not affect waters downstream of the Pajarito Plateau. The Rio Grande has not been listed as impaired due to copper in past 303(d) evaluations presented in New Mexico's integrated reports (IRs) (e.g., NMED 2018), neither above nor below confluences with Pajarito Plateau tributaries. Using New Mexico's current hardness-based copper criteria, the copper BLM, and the simplified SSWQC, copper concentrations in the Rio Grande were found not to exceed any criteria (more detail in Section 5.6). Therefore, a change on the Pajarito Plateau from the hardness-based criterion to the SSWQC would not adversely impact the Rio Grande downstream of its confluence with plateau tributaries.

No changes are proposed to existing or designated aquatic life uses or for non-aquatic life criteria such as irrigation, livestock watering, wildlife habitat, primary or secondary human contact, or drinking water. In addition, the proposed SSWQC change is not associated with new discharges of copper nor changes to existing discharges of copper.

2.1.3 Scientific methods for SSWQC

Under 20.6.4.10.D.4 NMAC, "a derivation of site-specific criteria shall rely on a scientifically defensible method, such as one of the following:

(a) the recalculation procedure, the water-effect ratio procedure metals procedure or the resident species procedure as described in the water quality standards handbook (EPA-823-B-94-005a, 2nd edition, August 1994)

(b) the streamlined WER procedure for discharges of copper (EPA-822-R-01-005, March 2001)

(c) the biotic ligand model as described in aquatic life ambient freshwater quality criteria – copper (EPA-822R-07-001, February 2007)

(d) the methodology for deriving ambient water quality criteria for the protection of human health (EPA-822-B-00-004, October 2000) and associated technical support documents; or

(e) a determination of the natural background of the water body as described in Subsection E of 20.6.4.10 NMAC."

In accordance with current EPA recommendations, the copper SSWQC described in this report were developed using the copper BLM and site-specific water chemistry to reflect copper bioavailability under varying water chemistry conditions on the Pajarito Plateau.

Prior to its publication of the 2007 copper criteria document, EPA recommended the water-effect ratio (WER) procedure to adjust copper criteria "to address more completely the modifying effects of water quality than the hardness regressions achieve" (EPA 2007a). EPA's Science Advisory Board found that compared to the WER procedure, the BLM can significantly improve predictions of copper toxicity to aquatic life across an expanded range of water chemistry parameters (EPA 2000).

As described in Section 5 of this report, EPA's BLM method was streamlined to substitute simple MLR equations for acute and chronic SSWQC[3] from a relatively complex software-based model. MLR is also a scientifically defensible method for generating WQC as a function of multiple water chemistry parameters (Section 4.3). Given the high degree of agreement between the MLR-predicted and BLM-based WQC (Section 5.4.2) and the scientific rigor associated with the BLM, the copper SSWQC presented in this report meet the 20.6.4.10.D.4 NMAC requirement that SSWQC be derived based on a scientifically defensible method.

2.1.4 Copper SSWQC petition

In accordance with WQCC regulations (20.1.6.200.A and 20.6.4.10.D(3) NMAC), any person may petition the WQCC to adopt SSWQC. WQCC regulations require that a petition for the adoption of SSWQC "be in writing and shall include a statement of the reasons for the regulatory change. The petition shall cite the relevant statutes that authorize the commission to adopt the proposed rules and shall estimate the time that will be needed to conduct the hearing. A copy of the entire rule, including the proposed regulatory change, indicating any language proposed to be added or deleted, shall be attached to the petition. The entire rule and its proposed changes shall be submitted to the commission in redline fashion, and shall include line numbers" (20.1.6.200.B NMAC). In addition, the regulations at 20.6.4.10.D(3) NMAC require that a petition do the following:

(a) Identify the specific waters to which the SSWQC would apply.

[3] The proposed SSWQC equations are analogous to the hardness-based equations used in the statewide WQS for copper, but the proposed SSWQC equations are more accurate because they include DOC and pH in addition to hardness.

(b) Explain the rationale for proposing the SSWQC.

(c) Describe the methods used to notify and solicit input from potential stakeholders and from the general public in the affected area, and present and respond to the public input received.

(d) Present and justify the derivation of the proposed SSWQC.

LANL will develop a draft petition for copper SSWQC based on: 1) conclusions and recommendations presented herein, 2) NMED and EPA comments on this report, and 3) input from other potential stakeholders, tribes, and the general public. The petition will include all information required under 20.1.6.200 and 20.6.4.10 NMAC for WQCC review.

2.1.5 Public involvement plan

A public involvement plan was developed to outline the general process and schedule for public, tribal, and stakeholder involvement in the development of the copper SSWQC. The complete plan is provided in Appendix C. Specific objectives of the plan are as follows:

- Identify potential stakeholders, tribes, and general public members who may be affected by the proposed copper SSWQC.
- Establish a process to present the proposed copper SSWQC to stakeholders, tribes, and the general public.
- Establish a process to receive and respond to input from stakeholders, tribes, and the general public on the proposed copper SSWQC.
- Develop a draft schedule for stakeholder, tribal, and general public engagement.

2.2 ANTIDEGRADATION

New Mexico's antidegradation policy (20.6.4.8 NMAC) applies to all surface waters of the state and to all activities with the potential to adversely affect water quality or existing or designated uses. Such activities include:

- Any proposed new or increased point source or nonpoint source discharge of pollutants that would lower water quality or affect the existing or designated uses
- Any proposed increase in pollutant loadings to a waterbody when the proposal is associated with existing activities
- Any increase in flow alteration over an existing alteration
- Any hydrologic modifications, such as dam construction and water withdrawals (NMED 2020a)

This petition does not propose new activities that could impact water quality or existing or designated uses on the Pajarito Plateau. Instead, it proposes updated copper WQC intended to more accurately achieve the level of protection for aquatic life stipulated by EPA guidance (Section 2.1.2). Therefore, an antidegradation review is not required for the proposed SSWQC.

If the proposed copper SSWQC are adopted by the WQCC into New Mexico's WQS, the SSWQC would establish the "level of water quality necessary to protect existing or designated uses" for any future antidegradation review related to any new proposed activity, as defined under New Mexico's antidegradation policy and in accordance with EPA recommendations for the protection of aquatic life uses (Section 2.1.2).

2.3 New Mexico WQS for Pajarito Plateau Surface Waters

Most water bodies on the Pajarito Plateau are classified in New Mexico WQS as ephemeral or intermittent waters (20.6.4.128 NMAC), which are designated as providing limited aquatic life use. According to NMAC, these water bodies are subject to acute criteria only. Only a few water bodies in the area are classified as perennial (20.6.4.121 and 20.6.4.126 NMAC), which are subject to both acute and chronic aquatic life criteria (i.e., Upper Sandia Canyon associated with wastewater treatment plant discharges; isolated segments of Cañon de Valle and Pajarito Canyon associated with local springs; and El Rito de los Frijoles in Bandelier National Monument). Unclassified surface waters (20.6.4.98 NMAC) are designated as providing a marginal warmwater aquatic life use, to which both acute and chronic aquatic life criteria apply. As discussed in Section 5, the proposed copper SSWQC include both acute and chronic criteria equations, so they can be applied as appropriate in accordance with NMAC surface water classifications.

NMED has assigned Assessment Units (AUs) to 50 surface water segments across the Pajarito Plateau, many of which are located within the Laboratory or receive discharges regulated by the Individual Permit (IP), the Multi-Sector General Permits (MSGP), the LANL industrial discharges, or the LAC wastewater treatment facility (WWTF) permit. New Mexico's most recent CWA §303(d)/305(b) IR for the 2020–2022 assessment cycle identifies multiple AUs impaired for aquatic life uses due to exceedances of NMED's hardness-based copper WQC, along with other causes (NMED 2020b). The IR impairment category provided for copper in these surface waters is 5/5B, defined as "impaired for one or more designated or existing uses and a review of the water quality standard will be conducted" (NMED 2018). The assessment rationale for the 2020 to 2022 IR explains that "[s]pecific impairments are noted as IR Cat 5B to acknowledge LANL's ongoing discussions and research regarding applicable water quality standards on the Pajarito Plateau for these parameters." The copper SSWQC described herein, being based on the best available science and current EPA recommendations, should provide more appropriate copper criteria for NMED's CWA §303(d)/305(b) assessments and other site assessments conducted by LANL.

2.4 NPDES Discharges

The NPDES permit regulates four principal types of discharges to Pajarito Plateau waters:

- Stormwater discharges associated with legacy contamination and industrial activities are regulated under the LANL's NPDES Storm Water IP (No. NM0030759).
- Stormwater discharges associated with current industrial activities are regulated under EPA NPDES MSGPs (Nos. NMR050011, NMR050012, and NMR050013).
- Industrial and sanitary wastewater and cooling water discharged from 11 outfalls are regulated under NPDES Permit No. NM0028355.
- Municipal sanitary wastewater discharged to Lower Pueblo Canyon by the LAC WWTF is regulated under NPDES Permit No. NM0020141.

These NPDES permits generally require water quality monitoring and certain actions based on concentrations of copper and other parameters. Current IP target action levels (TALs), MSGP benchmarks, and water quality-based effluent limits for copper applicable to Laboratory NPDES wastewater permits are based on New Mexico's hardness-based dissolved copper criteria (20.6.4.900 NMAC). In its 2019 draft IP Fact Sheet (EPA 2019), EPA suggested that BLM-based values may be considered for effluent benchmarks if BLM-based copper SSWQC are adopted into New Mexico WQS, and if NMED and N3B reach mutually agreeable BLM values through the annual sampling implementation plan. The copper SSWQC presented in this report are intended for eventual use in all NPDES permits and by NMED for CWA §303(d)/305(b) Integrated Assessments.

2.5 Threatened and Endangered Species

Possible effects of copper SSWQC on threatened and endangered species under the federal Endangered Species Act (ESA) were considered as part of this analysis. The Information for Planning and Consultation (IPAC) tool from the US Fish and Wildlife Service's Environmental Conservation Online System website (USFWS 2018) was used to identify listed species potentially present on the Pajarito Plateau and in downstream waters of the Rio Grande. The proposed scope for the SSWQC includes all watersheds from Guaje Canyon in the north to El Rito de Frijoles in the south, as well as from the headwaters of each canyon to the west and their confluences with the Rio Grande to the east. The following species were determined by the IPAC tool to be potentially present on the Pajarito Plateau or in Rio Grande waters (within a reasonable distance downstream of its confluence with Pajarito Plateau streams)[4]:

- New Mexico jumping mouse (*Zapus hudsonius luteus*)
- Mexican spotted owl (*Strix occidentalis lucida*)
- Southwestern willow flycatcher (*Empidonax traillii extimus*)
- Yellow-billed cuckoo (*Coccyzus americanus*)
- Jemez Mountains salamander (*Plethodon neomexicanus*)
- Rio Grande cutthroat trout (*Oncorhynchus clarkii virginalis*)
- Rio Grande silvery minnow (*Hybognathus amarus*)

Critical habitat for Mexican spotted owl and Jemez Mountains salamander would fall within the area potentially affected by the SSWQC (Map 3-1), and Rio Grande silvery minnow critical habitat is downstream of these waters. Each species is briefly evaluated and discussed in Appendix D. Based on these evaluations, it is not expected that implementation of the proposed SSWQC would adversely affect ESA-listed species (directly or indirectly) or their critical habitats.

In general, the species listed above are terrestrial and feed on terrestrial prey (Appendix D), suggesting that exposures to dissolved copper in Pajarito Plateau watersheds should be infrequent. Moreover, the copper BLM (and, by extension, the proposed SSWQC) represents criterion levels intended to be protective of sensitive aquatic species, including salmonids and cyprinids like the Rio Grande cutthroat trout and silvery minnow. It also protects potential prey items of these fish and other species.

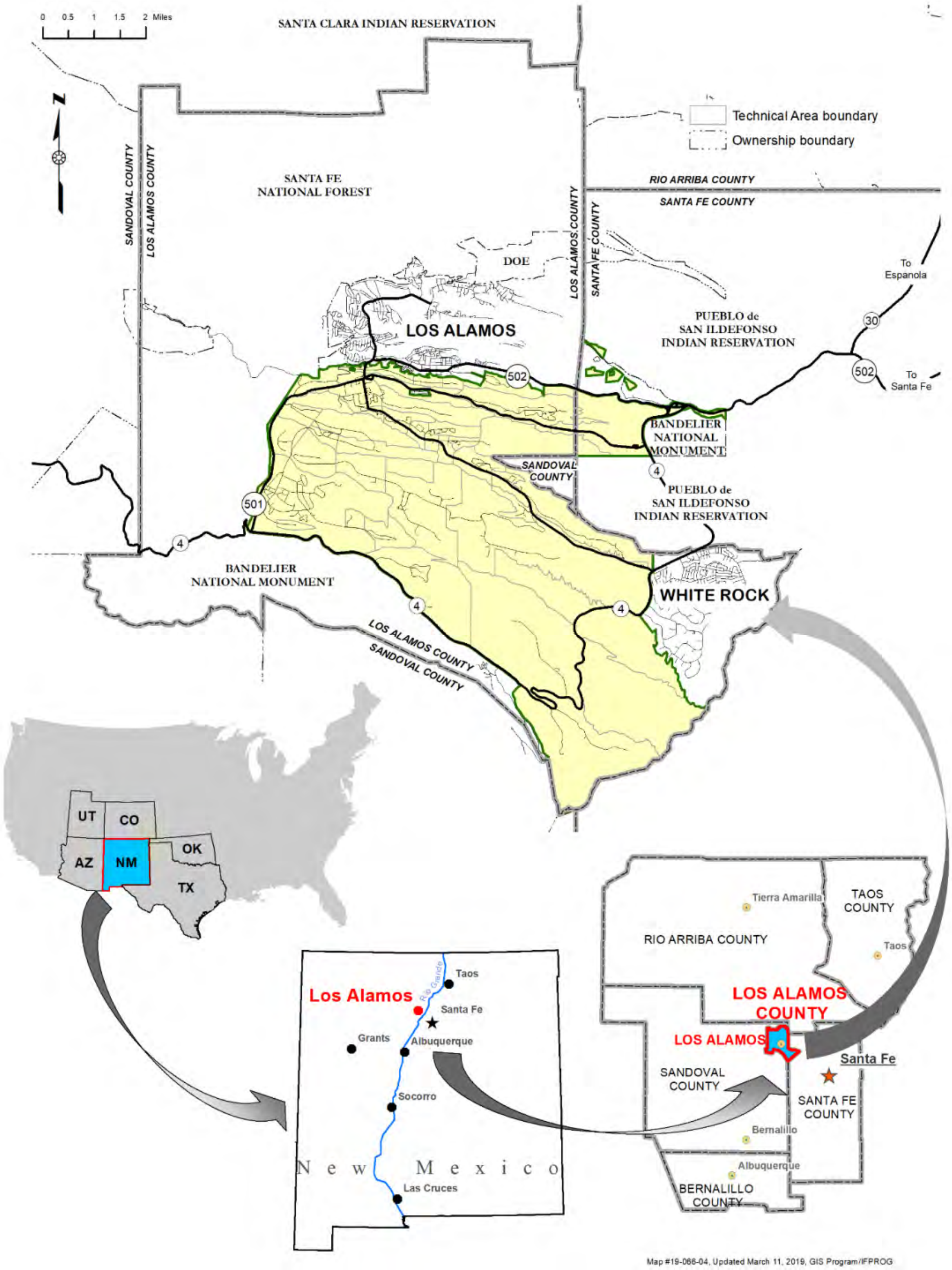
[4] A polygon was drawn using IPAC that included the Pajarito Plateau watersheds plus a 2 mile (approximate) buffer around the plateau (all watersheds). This captured the Rio Grande below the confluence with Pajarito Plateau watersheds.

3 Site Background

The following sections provide general background information on the physical setting, New Mexico's WQS, permitted discharges, and surface water monitoring programs for the Pajarito Plateau.

3.1 Geographic Setting

The Laboratory occupies approximately 36 square miles of US Department of Energy (DOE) lands in LAC in north-central New Mexico, approximately 60 miles north-northeast of Albuquerque and 25 miles northwest of Santa Fe (Figure 3-1). The general region encompassing the Laboratory, towns of Los Alamos and White Rock, Bandelier National Monument, San Ildefonso Pueblo lands, western slopes of the Jemez Mountains, and other surrounding areas is known, geographically, as the Pajarito Plateau. Lands north, west, and south of the Laboratory are largely undeveloped areas held by the Santa Fe National Forest, US Bureau of Land Management, Bandelier National Monument, and LAC (LANL 2013). The communities closest to the Laboratory are the towns of Los Alamos, located just to the north of the main Laboratory complex, and White Rock, located a few miles to the east-southeast.



Source: Hansen et al. (2020)

Figure 3-1. Geographic setting for LANL BLM dataset

3.2 GEOLOGIC SETTING

The Laboratory is situated on fingerlike mesas capped mostly by Bandelier Tuff. The Bandelier Tuff consists of ash fall, pumice, and rhyolite tuff that vary from 1,000 feet thick on the western side of the plateau to about 260 ft thick eastward above the Rio Grande (Broxton and Eller 1995). The mesa tops slope from elevations of approximately 7,800 feet on the flanks of the Jemez Mountains to about 6,200 feet at the mesas' eastern terminus above the Rio Grande Canyon. Natural background copper concentrations in Bandelier Tuff range from 0.25 to 6.2 mg/kg with a median of 0.665 mg/kg (Ryti et al. 1998).

Background copper concentrations in Pajarito Plateau surface waters were recently characterized by Windward (2020). Based on surface water samples collected by LANL between 2015 and 2018, Windward estimated that background dissolved copper concentrations draining from undeveloped landscapes (i.e., excluding the influence of urban runoff) are fairly low (≤ 5.6 µg/L).

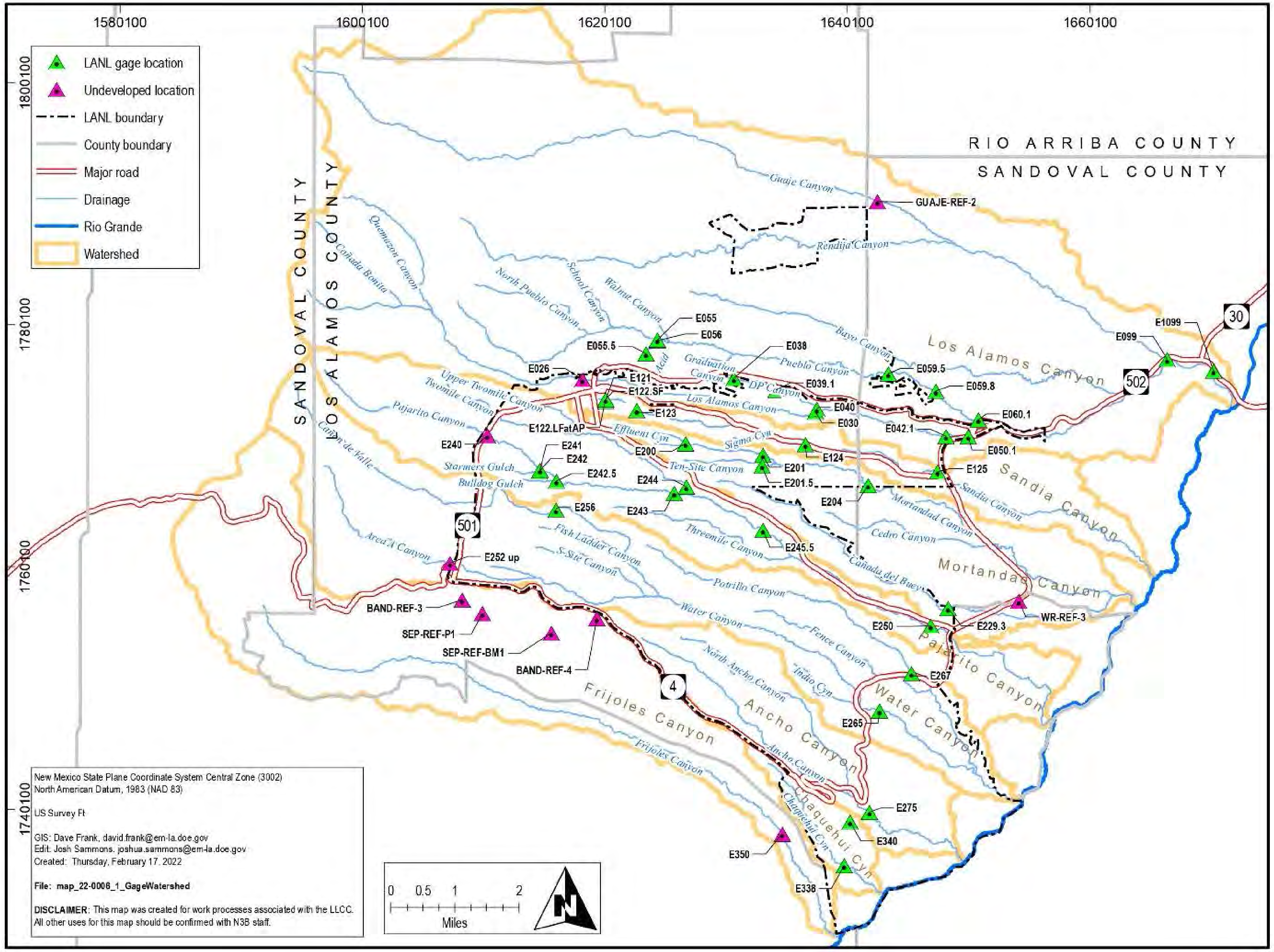
3.3 HYDROLOGIC SETTING

The Laboratory lies within a segment of the upper Rio Grande Basin denoted by the US Geological Survey eight-digit hydrologic unit code 13020101. The upper Rio Grande Basin is a large watershed (approximately 7,500 square miles) that generally flows from north to south. The New Mexico portion of the basin falls within seven counties: Rio Arriba, Taos, Santa Fe, Los Alamos, Sandoval, Mora, and San Miguel.

Surface water runs off the adjacent Jemez Mountains and Pajarito Plateau through steep and narrow canyons, flowing primarily southeast to the Rio Grande; however, surface water flows rarely reach the Rio Grande due to the limited flow durations and infiltration in canyon reaches upgradient of the Rio Grande (N3B 2020; Hansen et al. 2020). Most drainages on the Pajarito Plateau are currently classified as ephemeral or intermittent, because flow only occurs for limited periods in response to rainfall or snowmelt. Summer monsoonal thunderstorms are the sole contributors to flow in the many ephemeral waters, which otherwise remain dry for most of the year. A few canyons contain relatively short segments of intermittent and/or perennial flow attributable to springs, snowmelt, and industrial/municipal effluent discharges. Flows either represent stormflow (e.g., in response to precipitation events) or baseflow conditions, with baseflow generally being limited to perennial reaches and stormflow dominating other reaches.[5]

[5] For the purpose of this discussion, "baseflow" includes both natural baseflow and effluent. For example, "baseflow" in Upper Sandia Canyon is effluent dominated or effluent dependent.

The Laboratory encompasses seven major watersheds: Los Alamos, Sandia, Mortandad, Pajarito, Water/Cañon de Valle, Ancho, and Chaquehui Canyons. Many tributaries to these canyons are identified within the Laboratory as smaller sub-watersheds with other names. Additional sub-watersheds outside of the Laboratory include the 20.6.4.98 NMAC waters to the north (e.g., Pueblo, Bayo, Guaje, and Rendija Canyons and their tributaries). Frijoles Canyon, located to the south of the Laboratory, is another major watershed on the Pajarito Plateau. A depiction of the Pajarito Plateau, related water bodies, surface water sampling locations, the Laboratory, the towns of Los Alamos and White Rock, and Pueblo and County boundaries is presented in Map 3-1.



Map 3-1. **Sampling locations for BLM data on the Pajarito Plateau**

3.4 Sampling and Analysis Programs

This section provides a brief description of the sampling programs under which surface water quality data used to develop the copper SSWQC were collected. All samples included in the BLM dataset (Appendix A) were collected under sampling and analysis programs, validated, and reported previously to NMED under the various sampling programs described below.

3.4.1 Sampling

LANL conducts various surface water quality monitoring programs at many locations on the Pajarito Plateau. The programs are typically related to permit compliance monitoring and monitoring required under the NMED (2016) Compliance Order on Consent, although periodic investigative studies are also conducted to better understand and manage surface waters on the plateau. LANL is not obligated to sample and analyze for BLM parameters but has generally done so in response to EPA recommendations for developing aquatic life criteria for metals (EPA 2007a).[6]

Although surface water samples are sometimes collected as discrete grabs, most samples collected by LANL to date have been through its network of automated pump samplers (APS) located at various streamflow gaging stations. These devices are triggered when there is sufficient streamflow, often generated by a storm (typically during the summer monsoon season).[7] When there is sufficient flow, an internal pump initiates, drawing surface water into a series of sample bottles that remain in the APS until collected by a field technician (typically within 24 to 48 hours). Regardless of the sampling method, all samples are collected in pre-cleaned bottles to prevent contamination. The technician delivers the bottles to a sample processing facility, where each bottle is refrigerated, filtered, and/or chemically preserved as appropriate for the target analytes. Next, the sample is transferred to the sample management office and finally to LANL's contract laboratory for chemical analysis. This process is carried out by trained and qualified personnel under approved standard operating procedures (see Section 3.4.2). Quality control/quality assurance (QA/QC) measures are maintained during the sampling and transport processes, including the collection of field duplicates and maintenance of field blanks. Chain of custody (COC) forms are used to track the collection and delivery of samples to laboratories. Appendix A

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[6] BLM parameters that have been consistently analyzed by LANL include pH, DOC, calcium, magnesium, alkalinity, potassium, sulfate, and chloride. Temperature, %HA, and sulfide values are generally not determined and have been assumed, as discussed in Section 4.2.

[7] APS are generally in operation during the summer, when storm events result in sufficient flow; outside of this time period, samples cannot be collected consistently, so APS are not always in operation. Therefore, multi-seasonal datasets cannot be established for many streams on the Pajarito Plateau. Multi-seasonal data are available, however, for perennial reaches such as Upper Sandia Canyon (Appendix A).

provides COC numbers associated with each sampling event, as well as the sample collection and retrieval dates/times and laboratory receipt and analysis dates/times.

Due to the ephemeral/intermittent nature of many of the drainages, most surface water samples are collected during the late spring to early fall, during the monsoon season. However, samples are also collected during other parts of the year in perennial stream segments. Figure 3-2 summarizes the distribution of sampling over the year by month and season for the samples included in the BLM dataset (Appendix A).[8]

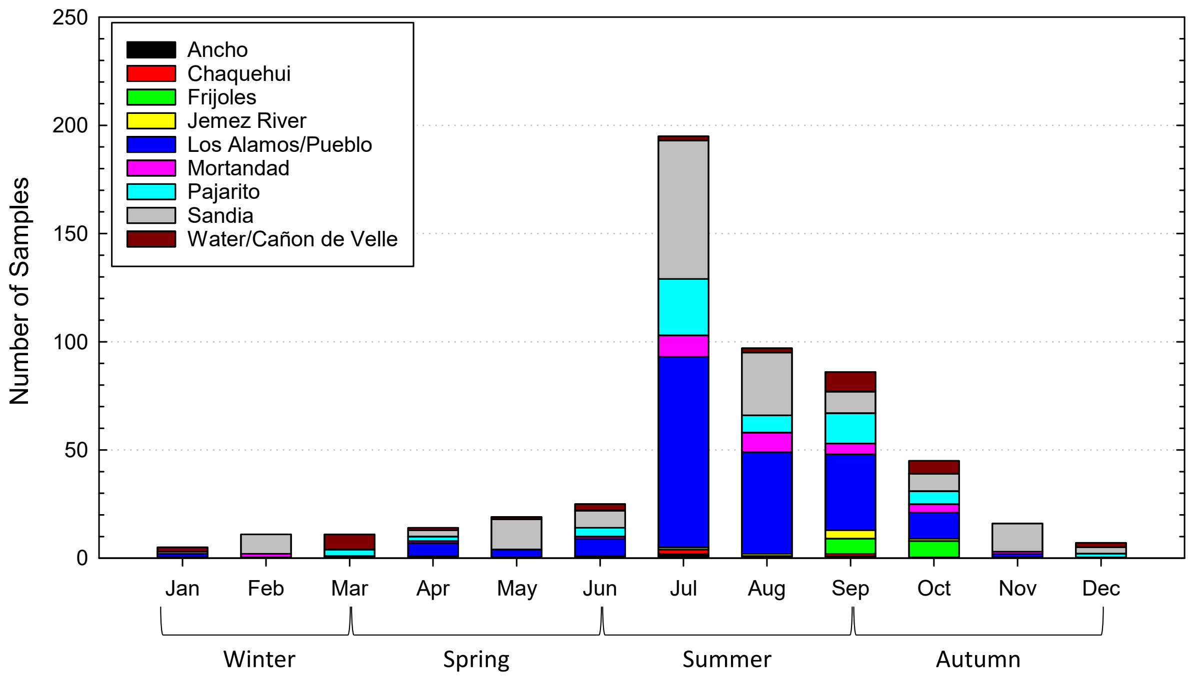


Figure 3-2. Distribution of BLM samples by watershed and season, 2005 to 2019

All BLM data from 2005 to 2019 were collected as part of five general programs in accordance with the laboratory and data validation procedures described in Section 3.4.2:

- Annual Site Environmental Report Program
- Los Alamos/Pueblo Canyon Sediment Monitoring Program
- Mortandad/Sandia Chromium Investigation and General Surveillance
- Sandia Wetlands Performance Monitoring Program
- Supplemental Environmental Program

[8] Figure 5-1 presents the sampling distribution similar to Figure 3-2 but across years instead of seasons.

Each of the sampling programs is associated with a sampling and analysis plan, which describes the sampling and analytical QA/QC for that program. Because they rely on similar samples and analytical data, these plans are comparable in scope and content.

3.4.2 Laboratory analysis and data validation

LANL contracted with several laboratories to analyze its surface water data between 2005 and 2019:

- General Engineering Laboratories, Inc., Charleston, South Carolina
- Environmental Sciences Division, Los Alamos, New Mexico
- Desert Research Institute, Reno, Nevada
- Cape Fear Analytical, Wilmington, North Carolina
- Brooks Applied Laboratories, Bothell, Washington

LANL's contract laboratories analyze the samples using standard analytical methods, usually EPA methods. The following methods are used:

- EPA 150.1 (pH)
- EPA 310.1 (alkalinity)
- SM-A2340B (hardness)
- SW-9060 (organic carbon)
- EPA 300.0 (anions – sulfate and chloride)
- EPA 200.7 and 200.8 and SW-846 methods 6010C, 6020, and 6020b (metals by inductively coupled plasma)

Each analytical method is considered appropriate and scientifically defensible for analysis of BLM parameters (EPA 2007b).

LANL's contract laboratories follow standard QA/QC procedures for analysis and data reporting and are accredited under the DOE Consolidated Audit Program for the analytes of interest. Detection and reporting limits are provided with samples, and non-detections are flagged by the laboratory and checked by independent data validators. Appendix A provides the detection status for each sample in the copper SSWQC database. When copper was not detected, reported results in Appendix A are equal to the detection limit.

N3B data validation is performed externally from the analytical laboratory and end-users of the data. This data validation process applies a defined set of performance-based criteria to analytical data that may result in the qualification of that data. Data validation provides a level of assurance, based on this technical evaluation, of the data quality.

Laboratory analytical data are validated by N3B personnel as outlined in N3B-PLN-SDM-1000, Sample and Data Management Plan; N3B-AP-SDM-3000, General Guidelines for Data Validation; N3B-AP-SDM-3014, Examination and Verification of Analytical Data; and additional method-specific analytical data validation guidelines. All procedures have been developed, as applicable, from the EPA QA/G-8 *Guidance on Environmental Data Verification and Data Validation* (EPA 2002), *Department of Defense/Department of Energy Consolidated Quality Systems Manual (QSM) for Environmental Laboratories* (DoD and DOE 2019), and the EPA national functional guidelines for data validation (EPA 2017, 2020).

N3B validation of chemistry data includes a technical review of the analytical data package. This review covers the evaluation of both field and laboratory QC samples, the identification and quantitation of analytes, and the effect of QA/QC deficiencies on analytical data, as well as other factors affecting data quality.

The analytical laboratory uploads the data as an electronic data deliverable to the N3B Environmental Information Management (EIM) database. The data are then validated both manually and using EIM's automated validation process. Validated results are reviewed by an N3B chemist before being fully transferred to the EIM database.

This validation follows processes described in the N3B validation procedures listed above. Validation qualifiers and codes applied during this process are also reviewed and approved by an N3B chemist to assess data usability. The EIM data are then made available to the public in the Intellus New Mexico database (Intellus 2019). Any data rejected during data validation were not used to develop the copper SSWQC. Additionally, any data in Intellus with a BEST_VALUE_FLAG reported as "N" was excluded.[9]

[9] Some surface water samples were analyzed multiple times for the same analyte, with each analytical result being reported in Intellus; one of those measurements may have been flagged as the "best." Data reported with a BEST_VALUE_FLAG of "Y" in Intellus were used to develop the copper SSWQC, whereas those with a flag of "N" were excluded.

4 Methods for Developing SSWQC

The following sections describe the technical and regulatory basis for the BLM and the resulting MLR-based SSWQC, which were developed using BLM input and output data (Appendix A).

4.1 Background on the BLM

The copper BLM is a software tool that mechanistically describes, and can predict, the bioavailability of copper under a wide range of water chemistry conditions observed in ambient surface waters. The copper BLM is scientifically robust and defensible, EPA recommended, and freely available. BLMs have been developed for metals in both freshwater and saltwater environments; however, to date, EPA has only released nationally recommended BLM-based WQC for copper. A general schematic for the BLM is depicted in Figure 4-1; arrows show the mechanistic relationships among various water quality parameters, the dissolved metal (“Me^{n+}”), and the biotic ligand, represented by the gill surface of an aquatic organism (or a homologous respiratory organ).

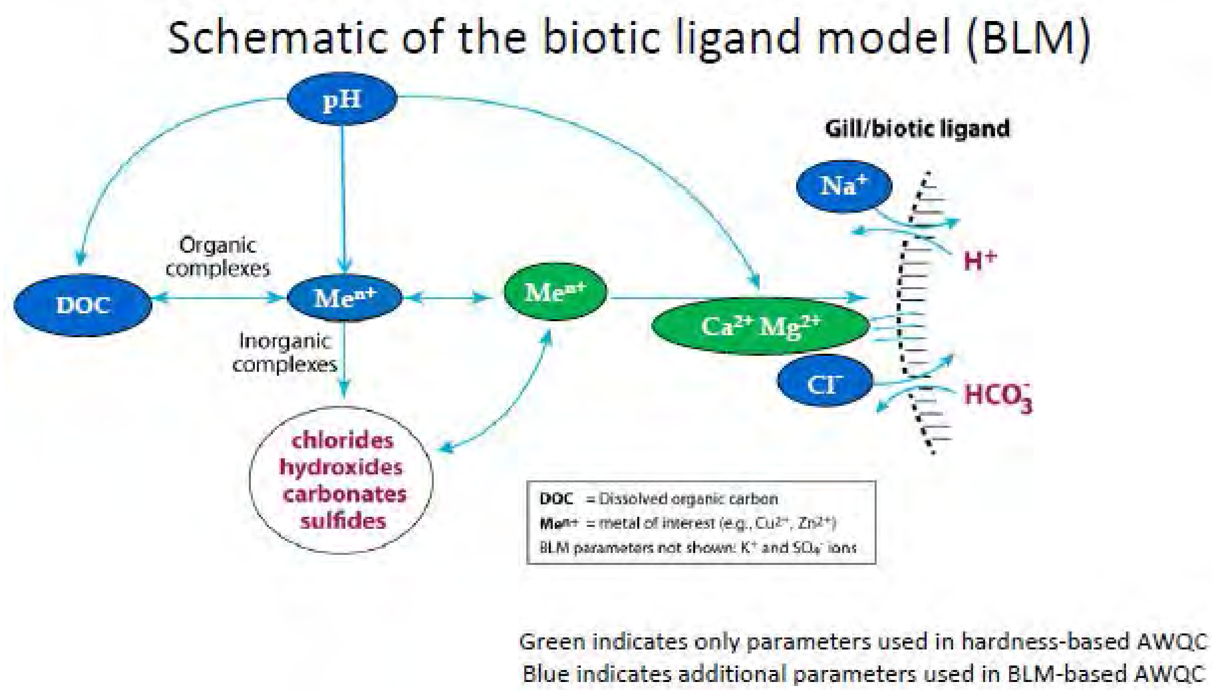


Figure 4-1. Schematic of the BLM

The BLM executable program that drives the Windows Interface version of the BLM software can be used to perform BLM calculations efficiently for large datasets. The Windows Interface version of the software (version 3.41.2.45) was used when developing this report.

The BLM's ability to incorporate metal speciation reactions and organism interactions allows for the prediction of metal effect levels associated with a variety of organisms over a wide range of water quality conditions. Accordingly, the BLM is a defensible and relevant method for deriving WQC across a broad range of water chemistry and physical conditions (EPA 2007a). It generates both acute (i.e., Criterion Maximum Concentration [CMC]) and chronic (i.e., Criterion Continuous Concentration [CCC]) criteria applicable to all aquatic life use categories specified in 20.6.4.10 NMAC.

The copper BLM is also applicable to stormwater flow and NPDES benchmarks. In 2019, EPA sponsored a study conducted by the National Academies of Sciences, Engineering, and Medicine's National Research Council for updating stormwater benchmarks under EPA's MSGP program (NAS 2019). Based on that study, EPA (2021) recommends that the copper BLM be used to derive stormwater benchmarks in accordance with EPA 304(a) guidance. EPA has also included stipulations for the use of the copper BLM at industrial facilities as part of the 2021 MSGP; the BLM may be used to show whether facility-specific discharge concentrations that exceed the generic MSGP copper benchmarks are in compliance.

4.2 Description of BLM Inputs and Functions

The copper BLM (EPA 2007a) utilizes 12 water quality parameters: pH, DOC, calcium, magnesium, sodium, potassium, sulfate, chloride, alkalinity, temperature, percent humic acid (%HA), and sulfide. While %HA is an input parameter, it is rarely measured in ambient surface waters, so the BLM user's guide recommends a default value of 10% (HydroQual 2007; Windward 2017). The selected default value for total sulfide was the recommended value from Windward (2019) of 1×10^{-10} mg/L, which is appropriate when sulfide data are not available. Total sulfide does not influence the copper BLM, however a small non-zero value is required to calculate BLM output. Measured copper concentrations are not needed to generate BLM WQC. All BLM inputs and outputs for Pajarito Plateau samples can be found in Appendix A.

EPA (2007a, 2016b) provides guidance for developing datasets suitable for generating BLM-based copper WQC, including how a given parameter can be estimated from other parameters or regional datasets or set to a default value. A general overview of these approaches is described below. Section 5.1 and Appendix B describe the development of the site-specific BLM dataset for the Pajarito Plateau.

Generally, measured concentrations in water samples that have been filtered through a 0.45-µm filter (i.e., operationally defined as dissolved concentrations) are used as BLM inputs. If it can be demonstrated that dissolved and total (unfiltered) concentrations of BLM inputs are similar, then total concentrations can be substituted for dissolved concentrations if the latter are not available for a given sample.

In addition to substitution approaches, it may be necessary to estimate concentrations for some BLM input parameters based on other measured parameters. For example, calcium and magnesium may be estimated from hardness, DOC may be estimated

from total organic carbon (TOC), and other cations or anions may be estimated from their relationships with conductivity or specific conductance. This estimation approach is contingent upon a demonstration that such estimates are appropriate and defensible.

Another approach to substituting missing BLM inputs makes use of the ecoregion-specific "default" estimates proposed by EPA (2016b). Oregon uses this approach to generate "default" copper WQC for purposes of initial screening assessments (Oregon DEQ 2016a, b; McConaghie and Matzke 2016), although state-specific datasets are used rather than EPA (2016b) values. This approach was not needed when aggregating data for the Pajarito Plateau for the analysis described herein, because sufficient water quality data were available (Section 5.1).

4.3 USE OF MLR IN DEVELOPING WQC

An MLR approach was used to develop a site-specific, three-parameter equation that accurately predicts BLM-based copper WQC for surface waters of the Pajarito Plateau using pH, DOC, and hardness values (Sections 5.3, 5.4, and 6). This approach parallels the one adopted in Georgia in 2016, whereby a two-parameter, BLM-based MLR equation was approved by EPA as the copper SSWQC for Buffalo Creek (Resolve 2015; EPA 2016a).[10] The MLR approach, where shown to be robust and accurate, significantly reduces sampling and analytical costs compared to using the full BLM, while still incorporating the BLM's scientific rigor.

EPA has commonly used linear regression to derive its nationally recommended WQC, most of which have been adopted in New Mexico WQS for metals and ammonia. EPA currently uses a simple linear regression with hardness as the independent variable to derive aquatic life criteria for cadmium, chromium, lead, nickel, silver, and zinc. EPA uses a two-parameter linear regression to derive aquatic life criteria for ammonia, using temperature and pH as independent variables. In 2018, EPA used a three-parameter MLR equation (using pH, DOC, and hardness) as the basis for its nationally recommended aquatic life criteria for aluminum (EPA 2018b). EPA is also currently evaluating MLRs as the potential bases of WQC for other metals (EPA 2018a). MLRs have been used by others to describe the effects of water chemistry on the bioavailability and toxicity of metals (EPA 1987; Esbaugh et al. 2012; Fulton and Meyer 2014; Rogevich et al. 2008), including in the development of copper WQC (Brix et al. 2017).

Thus, strong scientific and regulatory rationale exists for using the MLR approach to develop relatively simple equations that account for the effects of water chemistry on metal bioavailability.

[10] The two parameters used for Buffalo Creek were pH and DOC (Resolve 2015).

MLRs can be evaluated by how well they match BLM predictions, a process described in Section 5. An MLR equation that matches copper BLM WQC well yields criteria that are consistent with best available science and with EPA's nationally recommended WQC (EPA 2007a). Using an MLR equation has the benefit of being a transparent and readily available regulatory option that can incorporate EPA (2007a) BLM-based copper WQC into New Mexico WQS as SSWQC for surface waters of the Pajarito Plateau, without the need for BLM software and training.

5 Data Evaluation

This section describes the development of the Pajarito Plateau BLM dataset for the purpose of generating BLM-based copper WQC output. It also describes how those outputs were used to generate MLR equations for the Pajarito Plateau (i.e., the copper SSWQC).

5.1 DQO/DQA Process and BLM Dataset

In 2018, EPA's data quality objective/data quality assessment (DQO/DQA) process was used to select appropriate BLM datasets for several metals (including copper) and determine their usability for performing BLM-based WQC calculations consistent with EPA guidance (Windward 2018b; EPA 2007a).

Both Appendix B to this report and Windward's DQO/DQA report (2018b) provide additional information on the DQO/DQA process used to develop a scientifically defensible set of BLM input data. Each step of the 2018 DQO/DQA process pertaining to developing copper BLM inputs is summarized below:

1) **State the problem.** New Mexico's hardness-based copper criteria do not reflect the best available science regarding copper bioavailability and toxicity. Therefore, using the existing copper WQC may lead to erroneous conclusions about whether copper concentrations are protective of aquatic life, as well as erroneous decisions about management actions needed to protect aquatic life.

2) **Define study objectives.** The objectives were to identify and use appropriate data to generate BLM-based criteria for locations on or around the Pajarito Plateau near the Laboratory.

3) **Identify information inputs.** Inputs were sufficiently complete sets of BLM input parameters from discrete water sampling events in surface waters of the Pajarito Plateau. Water chemistry data used for BLM calculations were collected under a defined sampling plan using defensible sampling and analytical methods, QC review, and data validation procedures. The primary source of information for this evaluation was surface water monitoring data collected by LANL (Section 3.4; Appendix A; Appendix B, Section B2).

4) **Define study boundaries**. Temporal boundaries included the time periods over which sufficiently complete BLM input data exist for surface waters of the Pajarito Plateau. Surface water sampling events included either some form of dry weather baseflow (e.g., effluent, springs, and/or snowmelt) or stormflow generated by rainfall. Spatial boundaries included all surface water locations on the Pajarito Plateau in the vicinity of the Laboratory that have sufficient BLM datasets.

5) **Develop an analytical approach.** The overall analytical approach entailed 1) compiling a source dataset from LANL's EIM database, 2) aggregating and evaluating data to determine the extent to which BLM-based criteria can be generated for each discrete event in accordance with available EPA (2007b) guidance (Appendix B, Section B2), and 3) calculating BLM-based "instantaneous criteria" using the EPA (2007a) copper BLM (Section 5.2) for each discrete event with sufficient BLM inputs.

6) **Specify performance and acceptance criteria.** The performance and acceptance criteria for developing an appropriate dataset were primarily based on whether sufficient water chemistry data were available to generate BLM-based WQC for the locations of interest. Specifically, BLM-based calculations were performed only when, at a minimum, pH and organic carbon were measured for the same water sampling event. As appropriate, substitutions or estimations of missing BLM input parameters were conducted as possible from available data, for example using a mathematical relationship between dissolved and total concentrations, substituting the average concentration for a given location, and/or using EPA guidance for such estimations. Acceptance criteria included that 1) samples were collected in ambient surface waters (i.e., within AUs) rather than from storm water runoff locations in developed areas; 2) data used for BLM calculations were validated; and 3) models used for calculations were applicable and defensible for calculating WQC.

7) **Develop a plan for obtaining data**. As discussed in Section 3.4, surface water data, including BLM inputs, have been collected by LANL at many locations since 2005. To perform the analyses described above, water quality data from the EIM database associated with receiving water samples were queried by LANL contractors, and the results were provided to Windward as a spreadsheet. Supplemental water quality data for the Rio Grande were obtained from National Water Quality Monitoring Council's online Water Quality Portal database (National Water Quality Monitoring Council 2019).

The outcome of this process, when applied to LANL's surface water data, was the establishment of a BLM database with sufficient quality and quantity to develop SSWQC for Pajarito Plateau waters and to compare those criteria to existing criteria for copper and other metals. Staff from NMED[11] participated in the review of the DQOs and the 2018 DQO/DQA report.

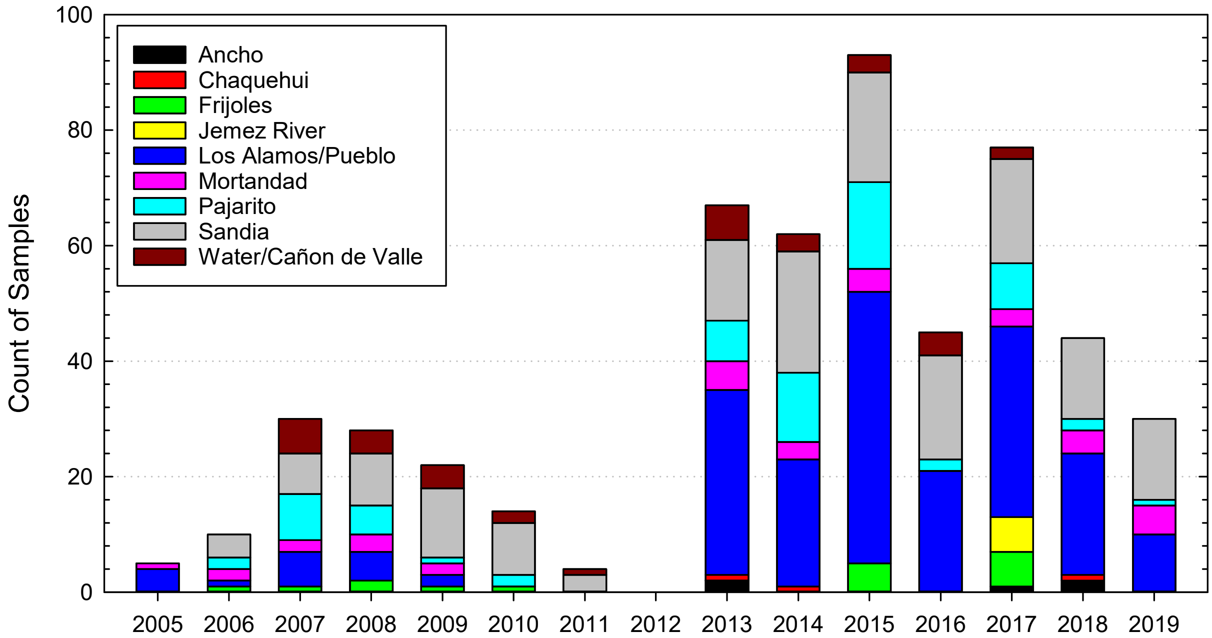
[11] NMED staff from the SWQB and DOE Oversight Bureau participated in kickoff meetings in March 2018, and they submitted comments on the draft DQO/DQA report that were addressed in the April 2018 BLM DQO/DQA report. NMED staff also participated in an October 2018 webinar with EPA Region 6 staff to review and discuss the BLM findings and their potential use as stormwater monitoring TALs for copper, lead, and zinc in the context of the IP.

For this demonstration, the 2018 DQO/DQA process was applied to a water quality dataset that included BLM data collected through 2019 (i.e., two additional years of monitoring data not assessed in the 2018 DQO/DQA report). The complete BLM dataset for the Pajarito Plateau is provided in Appendix A. The source dataset was generated by LANL/N3B (Section 3.4), uploaded to the EIM database, and then exported and provided to Windward by N3B. In addition to analytical data, N3B provided information about sampling locations to support interpretation of the BLM dataset. This information included major and minor watershed names, location classifications related to land use (i.e., undeveloped or downstream of a LANL site), and information on the type of water sample (e.g., surface water, snowmelt, persistent flow, or storm water runoff).

After receiving the source dataset from N3B, Windward aggregated water quality data to establish sufficient input parameters to generate BLM-based copper WQC for each discrete sampling event. Further information on the DQO/DQA process and data aggregation steps used to construct the complete BLM dataset for the Pajarito Plateau is provided in Appendix B (Section B2).

The complete BLM dataset for the Pajarito Plateau spans the period from 2005 to 2019 and includes a total of 531 discrete samples collected from 50 locations across 9 large watersheds.[12] Figure 5-1 shows a breakdown of when and where the 531 BLM samples in the final dataset were collected. Map 3-1 shows each surface water monitoring location. Figures 5-2 and 5-3 show the distributions of water quality parameters in the full dataset (Appendix A).

[12] Ultimately, 517 samples were used for MLR development; 14 samples with pH, DOC, and/or hardness values outside the prescribed ranges for the BLM were removed.



Note: No samples in the final BLM dataset were collected in 2012 due to drought conditions.

Figure 5-1. Distribution of BLM samples by watershed and over time, 2005 to 2019

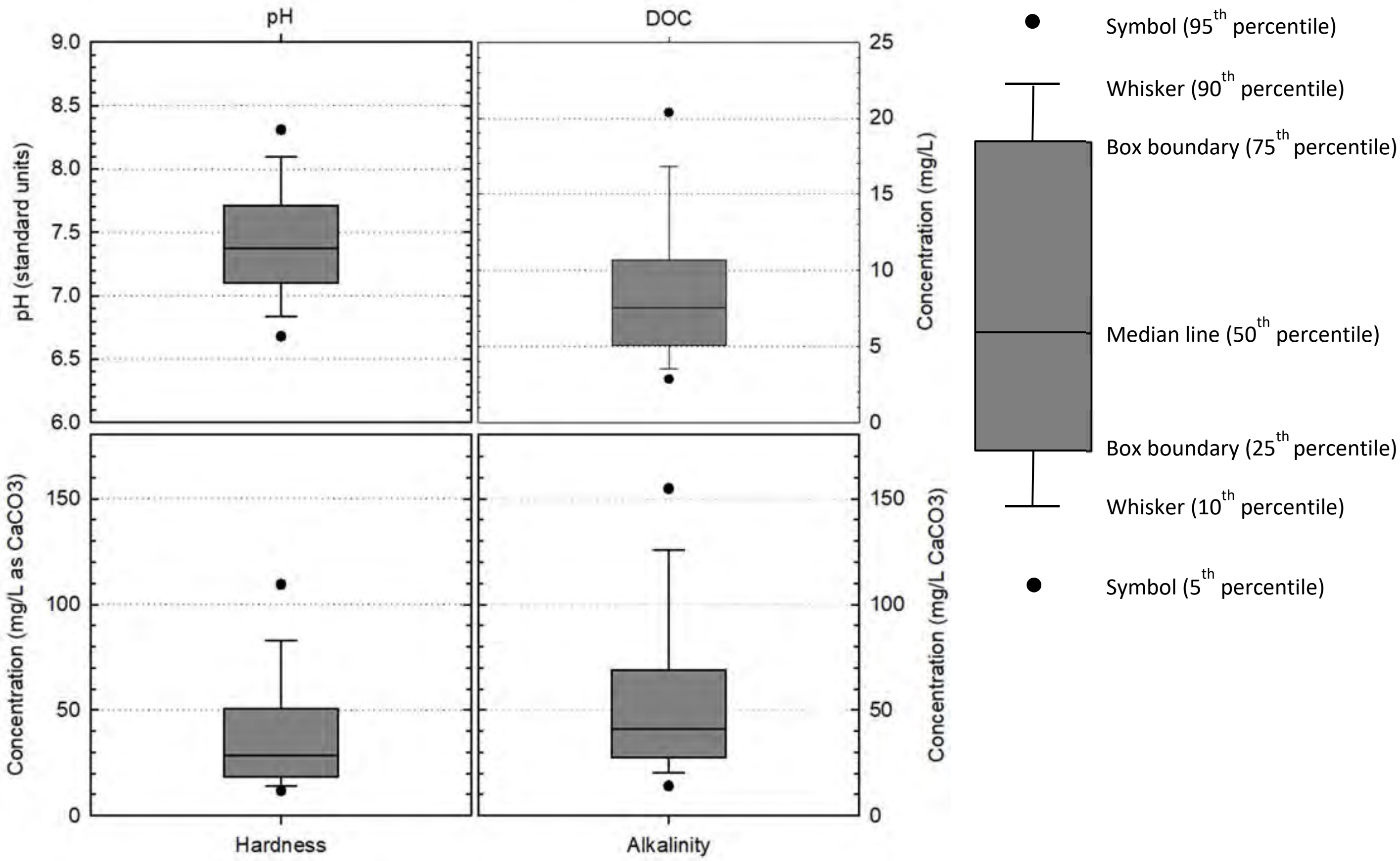
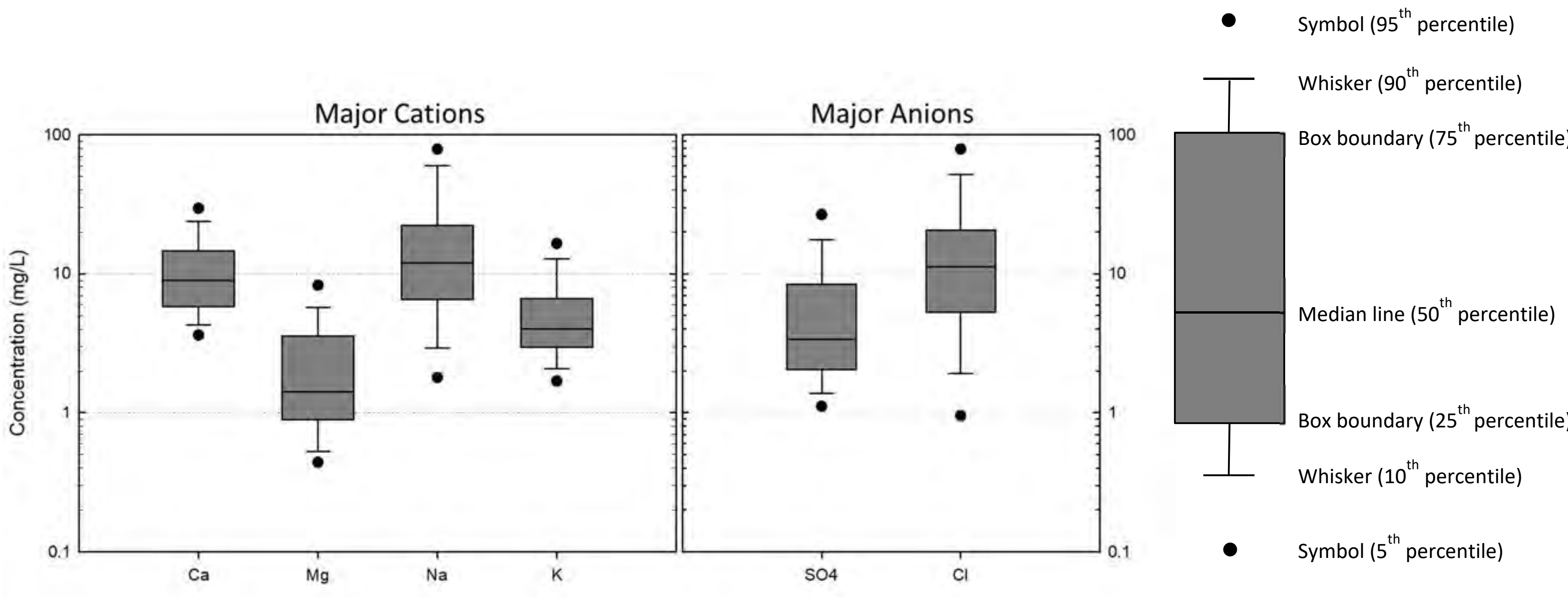


Figure 5-2. Distributions of water quality inputs to the MLR and/or BLM



Note: The following water chemistry parameters are shown: calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), sulfate (SO4), and chloride (Cl).

Figure 5-3. Distributions of major cation and anion inputs to the BLM

As discussed in this report and in Appendix B, hydrology was investigated in detail when developing copper SSWQC, because of the various hydrological classifications of surface waters on the Pajarito Plateau (i.e., ephemeral, intermittent, and perennial). According to New Mexico WQS, chronic and acute WQC apply in specific watersheds based on their respective hydrologic classifications, so the proposed acute and chronic SSWQC, if adopted, would apply similarly. For the purposes of developing and testing MLR equations to accurately estimate BLM WQC, hydrology data were characterized using existing NMAC hydrologic classifications for surface waters of the Pajarito Plateau. Table 5-1 shows a tabular breakdown of samples by major watershed and current NMAC hydrologic classification. Additionally, Appendix B (Section B5.2.3) provides an investigation of potential updated classifications based on the most recent hydrology protocol efforts by NMED and LANL.

Table 5-1. New Mexico WQS hydrologic classification assignments for the BLM dataset by major watershed

Major Watershed	NMAC Hydrological Classification			N by Watershed
	Ephemeral/ Intermittent (20.6.4.128)	Default Intermittent (20.6.4.98)	Perennial (20.6.4.121/ 20.6.4.126)	
Ancho	5	0	0	**5**
Chaquehui	3	0	0	**3**
Frijoles	0	9	8	**17**
Jemez River	0	6	0	**6**
Los Alamos/Pueblo	142	62	0	**204**
Mortandad	28	6	0	**34**
Pajarito	62	0	3	**65**
Sandia	8	0	154	**162**
Water/Cañon de Valle	4	12	19	**35**
N by Hydrology Class	**252**	**95**	**176**	**531**

N – sample size
BLM – biotic ligand model
NMAC – New Mexico Administrative Code
WQS – water quality standard

5.2 BLM Execution

The final BLM dataset (Section 5.1; Appendix A) was input into the copper BLM software (version 3.41.2.45) (Windward 2018a) to generate acute and chronic BLM-based WQC for all samples.[13] These WQC were equivalent to EPA's 2007 copper WQC for freshwater (EPA 2007a) and were used in conjunction with water quality parameters to develop the copper MLR equations. The reduction of the full suite of

[13] The most recent BLM software is accessible through the Windward website: https://www.windwardenv.com/biotic-ligand-model.

BLM parameters to pH, DOC, and hardness for use in the MLR approach is summarized in Sections 5.3 and 5.4.

5.3 BLM Simplification

LANL is proposing MLR equations that will predict BLM-based copper WQC for surface waters of the Pajarito Plateau in the vicinity of the Laboratory. This approach acknowledges both the advantages of the BLM—incorporating the effects of multiple water-quality parameters on copper bioavailability and toxicity—and the challenges—measuring BLM parameters across a large area with a range of water quality and flow conditions. Estimating BLM copper WQC accurately using fewer parameters than the full list of 12 inputs will facilitate copper evaluations.

As described in Section 5.1, site-specific water quality data were collated from 531 samples from 50 locations from 2005 to 2019 (Appendix A). A set of 517 samples spanning 8 watersheds[14] was carried forward to the first round of MLR modeling; 14 samples were removed due to DOC, hardness, or pH concentrations being outside of the prescribed ranges (Table 5-2) for the BLM. Thus, the water quality conditions in Pajarito Plateau surface water samples spanned the entire range of conditions considered reasonable for use in the copper BLM. Modeling methods are summarized in Section 5.4.1 and detailed in Appendix B.

Table 5-2. Prescribed ranges for BLM input parameters

BLM Parameter	BLM Prescribed Range	
	Minimum	Maximum
DOC	0.05	29.65
Hardness	7.9	525
pH	4.9	9.2

Source: Windward (2019)

BLM – biotic ligand model

DOC – dissolved organic carbon

Table 5-3 presents the results of a Spearman correlation analysis (i.e., Spearman rho values) that further substantiate the importance of pH, DOC, and hardness in calculating SSWQC for the Pajarito Plateau. This table illustrates correlations among the three parameters and other BLM input parameters.

[14] The six samples from the Jemez River watershed (Table 5-1) were not carried forward to the MLR analysis because hardness concentrations were < 7.9 mg/L as calcium carbonate (the minimum prescribed concentration for the BLM). Thus, the number of watersheds in the MLR dataset was eight, not nine.

Table 5-3. Spearman correlation analysis results (rho)

Parameter	BLM CMC	BLM CCC	pH	DOC	Hardness	Calcium	Magnesium	Sodium	Potassium	Sulfate	Chloride	Alkalinity
BLM CMC	–	–	0.57	0.54	0.42	0.41	0.43	0.38	0.57	0.45	0.36	0.55
BLM CCC	–	–	0.57	0.54	0.42	0.41	0.43	0.38	0.57	0.45	0.36	0.55
pH	0.57	0.57	–	-0.29	0.57	0.57	0.53	0.5	0.36	0.5	0.44	0.66
DOC	0.54	0.54	-0.29	–	-0.09	-0.09	ns	-0.17	0.23	ns	-0.14	ns
Hardness	0.42	0.42	0.57	-0.09	--	0.99	0.92	0.63	0.63	0.73	0.54	0.83
Calcium	0.41	0.41	0.57	-0.09	0.99	–	0.86	0.6	0.6	0.69	0.52	0.82
Magnesium	0.43	0.43	0.53	ns	0.92	0.86	–	0.64	0.71	0.78	0.55	0.8
Sodium	0.38	0.38	0.5	-0.17	0.63	0.6	0.64	–	0.7	0.8	0.91	0.62
Potassium	0.57	0.57	0.36	0.23	0.63	0.6	0.71	0.7	–	0.72	0.61	0.66
Sulfate	0.45	0.45	0.5	ns	0.73	0.69	0.78	0.8	0.72	–	0.76	0.68
Chloride	0.36	0.36	0.44	-0.14	0.54	0.52	0.55	0.91	0.61	0.76	–	0.54
Alkalinity	0.55	0.55	0.66	ns	0.83	0.82	0.8	0.62	0.66	0.68	0.54	–

Note: All values are Spearman correlation coefficients, which can range from -1 to 1. Only significant correlations are reported (alpha = 0.05); color shading indicates relative strength of correlation (with blue being positive values and red being negative). BLM CMC and CCC correlations are identical because the acute and chronic BLM values differ only by an acute-to-chronic ratio.

– Not Applicable

BLM – biotic ligand model

CMC – criterion maximum concentration

CCC – criterion continuous concentration

DOC – dissolved organic carbon

ns – not significant

Table 5-3 shows that the strongest correlations with BLM output (i.e., CMC and CCC) are for pH (rho = 0.57), potassium (rho = 0.57), alkalinity (rho = 0.55), and DOC (rho = 0.54). Thus, pH and DOC are reasonable to retain for a simplified model, because they have relatively strong correlations and are well supported by the literature regarding mechanisms affecting copper bioavailability (i.e., copper speciation and complexation). While hardness is marginally less correlated with BLM output (rho = 0.44) than are other parameters, hardness is significantly correlated ($p < 0.05$) with pH, calcium, magnesium, sodium, potassium, sulfate, chloride, and alkalinity. Consequently, including hardness in the simplified version incorporates the influence of these parameters on BLM output and builds upon New Mexico's current hardness-based copper criteria in response to which LANL has already collected a substantial amount of hardness data.

While potassium is relatively correlated with the BLM output, sensitivity analyses of the copper BLM established that it is not as mechanistically significant as pH, DOC, or hardness.[15] In their development of a copper BLM specific to the cladoceran *Daphnia magna*, De Schamphelaere and Janssen (2002) evaluated the influence of calcium, magnesium, sodium, potassium, and pH and found that potassium was the only parameter considered that did not affect toxicity. Brix et al. (2017) found that MLR models using only pH, DOC, and hardness (without other parameters) predicted copper toxicity values with a level of accuracy comparable to that of the copper BLM. From a statistical standpoint, parsimonious models are preferable to those including many intercorrelated variables, which can result in "overfitting."[16] Therefore, the importance of potassium for modeling BLM output was viewed skeptically when developing MLRs.

5.4 MLR Equation Development

This section describes the development of acute and chronic MLR equations using BLM input parameter data and corresponding BLM outputs (i.e., BLM-based WQC). For the MLR evaluations, DOC and hardness were transformed using the natural logarithm. This transformation was not required for pH, since it is already on a logarithmic scale. The evaluations were conducted primarily for the acute BLM WQC, because EPA (2007a) applies an acute-to-chronic ratio to generate chronic BLM WQC. As a result, the acute and chronic BLM WQC for copper vary by a constant factor (i.e., 1.61), regardless of water chemistry. Therefore, the following evaluations regarding the development of a best-fit MLR equation are applicable to both acute and chronic copper WQC.

[15] Personal communication, Robert Santore (developer of the copper BLM).

[16] An overfitted MLR will generally predict the underlying dataset better than a simpler model, but it is less likely to predict future data with similar accuracy. Overfit models are overly specific.

5.4.1 Methods

Many candidate MLRs were developed, evaluated, and compared using standard statistical and visual methods, which included statistics related to each model's goodness-of-fit (e.g., adjusted R^2) and model assumptions (e.g., tests of the normality and homoscedasticity of residuals). Visual tools were used to evaluate model fit and to facilitate model refinements (Appendix B, Section B4).

The development of models followed several general steps iterated over several rounds of modeling. First, a basic model was tested that contained only pH, DOC, and hardness, consistent with previously developed MLR models (Brix et al. 2017) and the simplified BLM (Windward 2019). These three water quality parameters affect copper speciation (e.g., pH), complexation with the free cupric ion ($copper^{2+}$) (e.g., DOC), and competition with copper at a site of uptake by the organism (e.g., $calcium^{2+}$ represented by hardness and $hydrogen^{+}$ represented by pH). As such, they capture the primary mechanisms affecting copper bioavailability that underpin the copper BLM.

Once this baseline model was established, various other, more complex models that included additional parameters were developed. For example, models included different slopes and/or intercepts for ephemeral/intermittent, intermittent, and perennial NMAC classifications. The development of these models was followed by a stepwise regression step, wherein the statistical software was allowed to test many permutations of the larger model by adding or removing the hydrologic slopes and intercepts and checking the goodness-of-fit of each permutation.[17] This step provided information about which of the variables in the most complex model might be important and which could be excluded during the model refinement step. The final step, model refinement, involved both the removal of unimportant variables and the addition of a new variable, squared pH (pH^2), to eliminate patterns observed in the model residuals (Figure 5-4).

5.4.2 Results

A detailed discussion of the development of MLR equations is provided in Appendix B, Section B4. This section provides a summary of those findings and the stepwise MLR analyses that led to the proposed MLR equations for copper SSWQC.

As noted in Section 5.4.1, MLRs were developed over several rounds. The first round started with a simple model using pH, DOC, and hardness as the independent variables to predict BLM-based WQC. This model resulted in a very high adjusted R^2 of 0.969, indicating that 96.9% of the variation in BLM-based WQC can be accounted for by these three parameters.

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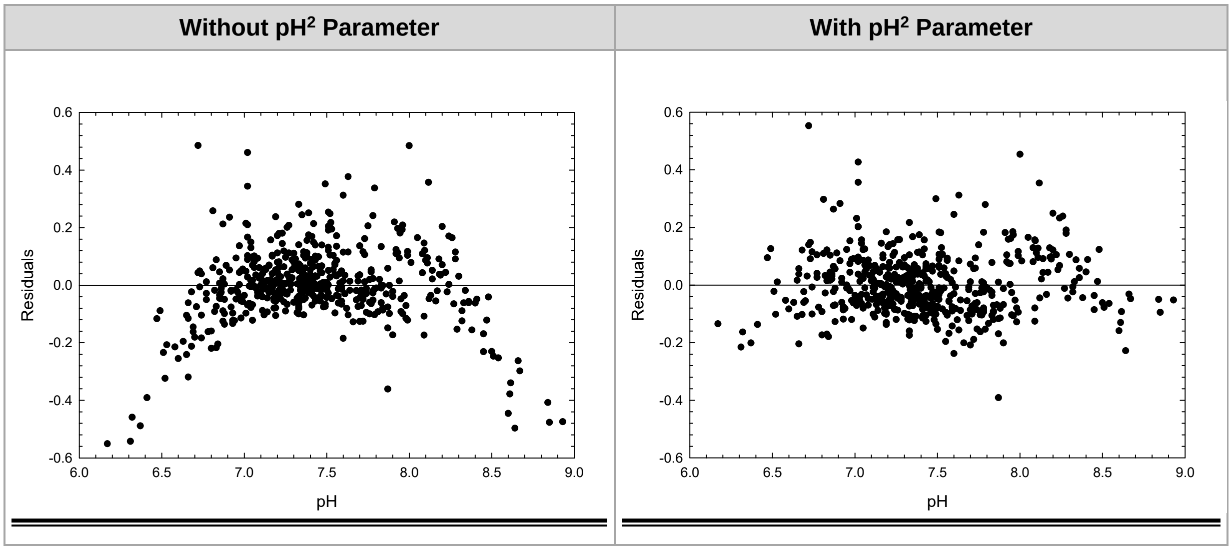
[17] This step was limited to hydrological classification parameters, slopes, and intercepts. DOC, pH, and hardness were retained throughout the stepwise analysis.

More complex models including pH, DOC, and hardness, as well as hydrology-specific slopes and intercepts for the ephemeral/intermittent, intermittent, and perennial classifications, were considered in the second round. While evaluating this model structure, it was observed that MLR model residuals (i.e., difference between BLM WQC and MLR-predicted WQC) and pH had a curvilinear relationship (Figure 5-4, left panel). To address this, a pH^2 term was added to the model in the third round; this eliminated the curvilinear pattern in residuals (Figure 5-4, right panel).



Note: Horizontal line at a residual of zero indicates perfect prediction.

Figure 5-4. Comparison of MLR model residuals with and without a pH^2 parameter

After including the pH^2 term, models without hydrology factors were also developed as part of the third round of modeling. Comparisons of summary statistics among these various models (Table 5-4), analysis of residuals (Appendix B, Section B4), and consideration of the magnitudes of differences among models led to the conclusion that the use of hydrology-specific slopes and intercepts did not result in better MLR equations compared to the use of less complex (i.e., more parsimonious) models. For example, after removing all hydrological classification parameters from the MLR in the third round of modeling, the adjusted R^2 changed from 0.983 to 0.980, meaning that hydrology classification explained only 0.3% of the variation not already explained by pH, DOC, and hardness. From a practical standpoint, the added complexity of hydrological classification was not needed to accurately predict BLM output. Moreover, because the NMAC classes are subject to change over time (e.g., default intermittent waters are potentially reclassified through the hydrology protocol process), to include hydrologic classification could lead to unnecessary ambiguity in future applications of the MLR.

Table 5-4. Summary statistics of MLR models fit to BLM WQC

Model Description	Development Method[a]	Adjusted R^2	Predicted R^2	AIC	BIC	Shapiro-Wilk Test p-value[b]	Scores Test p-value[c]
Simplest model; includes pH, DOC, and hardness only (no distinction in hydrology)	full	0.969	0.968	-614	-593	<0.001	0.249
Hydrology slopes and intercepts	full	0.973	0.971	-677	-621	<0.001	0.751
	AIC	0.973	0.971	-681	-643	<0.001	0.704
	BIC	0.973	0.971	-681	-643	<0.001	0.704
Hydrology slopes and intercepts; pH^2 added	full	0.984	0.981	-928	-860	<0.001	0.0476
	AIC	0.984	0.981	-928	-860	<0.001	0.0476
	BIC	0.983	0.981	-918	-876	<0.001	0.00332
Hydrology intercepts only (slopes excluded); pH^2 term always included	full	0.982	0.982	-899	-865	<0.001	0.0204
	AIC	0.982	0.982	-899	-865	<0.001	0.0204
	BIC	0.982	0.982	-899	-865	<0.001	0.0204
No distinction in hydrology; pH^2 term always included; final models (proposed MLRs for copper SSWQC)	full (acute)	0.980	0.979	-833	-808	<0.001	0.083
	full (chronic)	0.980	0.979	-833	-808	<0.001	0.083

[a] Development methods are divided into "full" models (includes all variables indicated in model description) or AIC/BIC stepwise regression models.

[b] Shapiro-Wilk test for normality of residuals; $p < 0.05$ indicates non-normality.

[c] Scores test for homogeneity of residuals; $p < 0.05$ indicates non-constant variance (i.e., heteroscedasticity).

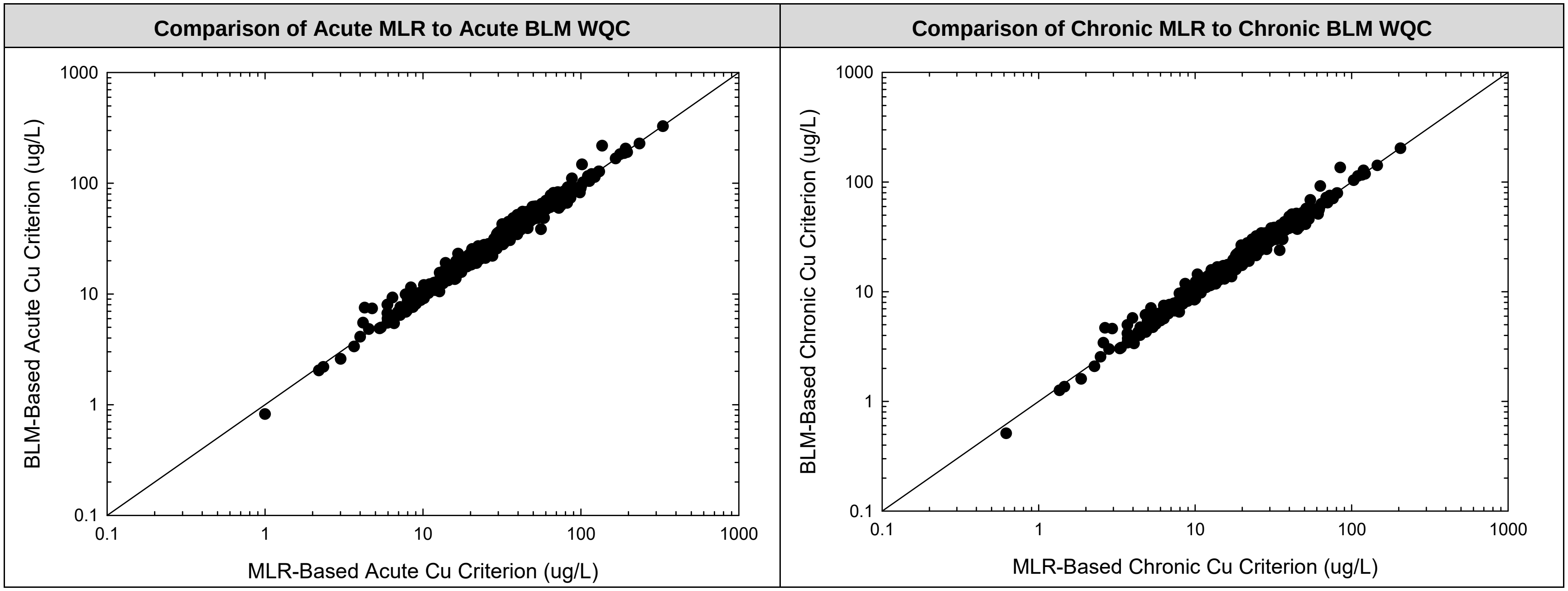
AIC – Akaike's Information Criterion
BIC – Bayesian Information Criterion
BLM – biotic ligand model
DOC – dissolved organic carbon
MLR – multiple linear regression
SSWQC – site-specific water quality criterion
WQC – water quality criterion

After demonstrating that an MLR model including hydrological class is not a substantial improvement over a more parsimonious model, and after including a pH^2 parameter to address residual patterns, Equations 1 and 2 were selected as SSWQC.

$$\boldsymbol{CMC = exp(-22.914 + 1.017 \times ln(DOC) + 0.045 \times ln(hardness) + 5.176 \times pH - 0.261 \times pH^2)}$$ **Equation 1**

$$\boldsymbol{CCC = \exp(-23.391 + 1.017 \times ln(DOC) + 0.045 \times ln(hardness) + 5.176 \times pH - 0.261 \times pH^2)}$$ **Equation 2**

Figure 5-5 shows comparisons of MLR-based SSWQC calculations to the equivalent BLM calculations for the Pajarito Plateau dataset. The figure shows that the SSWQC and BLM calculations are very similar between the two approaches (adjusted $R^2 = 0.980$ for the acute and chronic MLRs) and values are distributed evenly across the solid diagonal 1:1 line representing perfect agreement. Therefore, the three-parameter MLR equations provide highly accurate results. In addition, more points fall above the 1:1 line (n = 261) than below (n = 256) in Figure 5-5, indicating that overall, the proposed copper SSWQC equations provide more conservative copper WQC for the Pajarito Plateau than the BLM software.

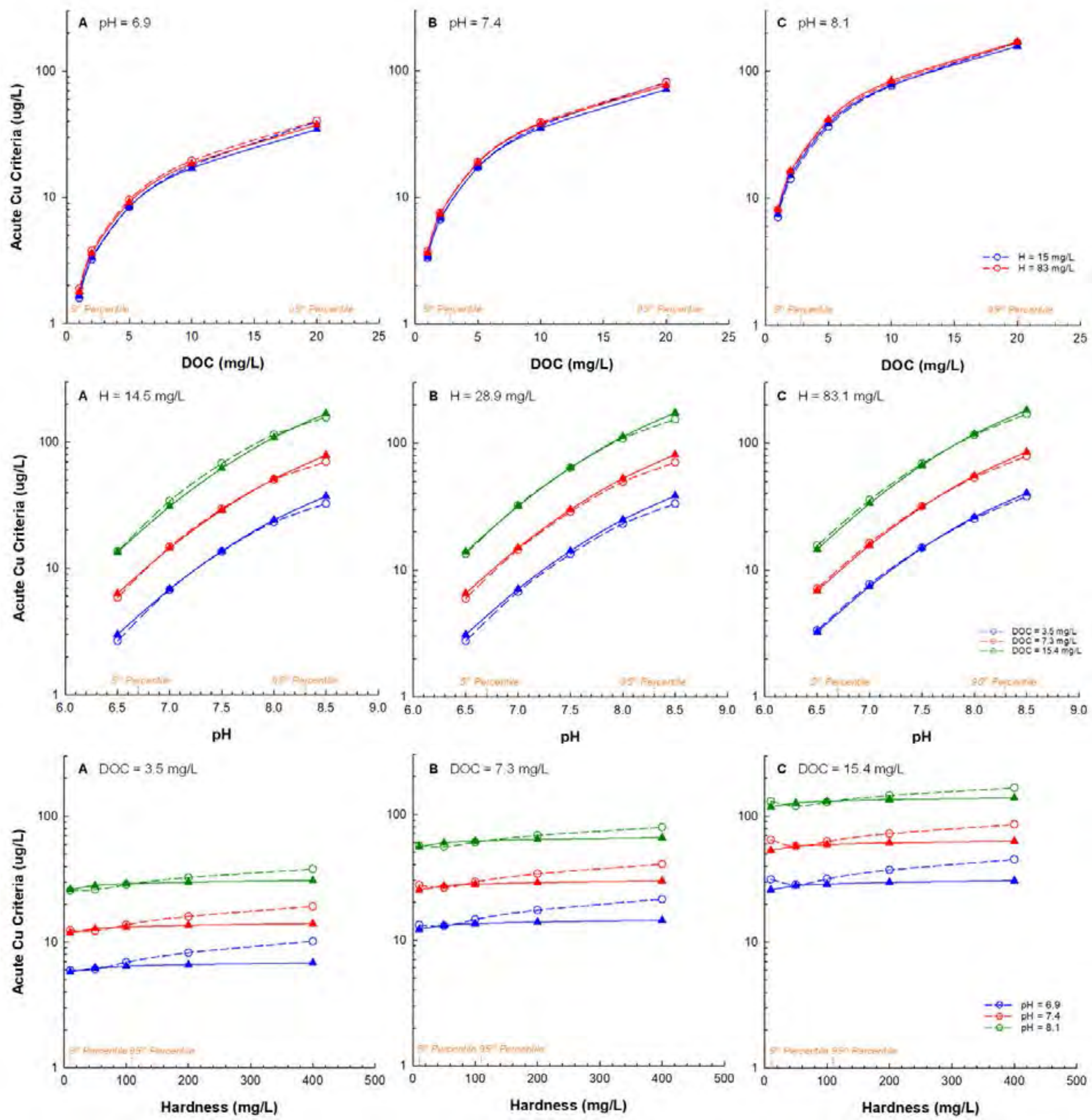


Note: Solid line represents a 1:1 relationship (perfect agreement).

N = 517 samples (BLM dataset for the Pajarito Plateau excluding samples outside the BLM prescribed ranges for pH, DOC, and hardness)

Figure 5-5. Comparison of proposed acute and chronic copper SSWQC predictions to acute and chronic BLM WQC

Figure 5-6 presents an additional comparison of MLR- and BLM-based copper WQC across varying concentrations and combinations of DOC, pH, and hardness.



Note: BLM-based criteria are shown as dashed lines and open circles. MLR-based acute criteria are shown as solid lines and triangles. Blue, red, and green plots represent the 10th, 50th, and 90th percentiles, respectively, in the BLM dataset for the Pajarito Plateau. The 5th and 95th percentiles for each parameter are shown in orange on each x-axis. For comparative purposes, BLM criteria were generated with the “simplified site chemistry” input option using median ion ratios in the site-specific dataset.

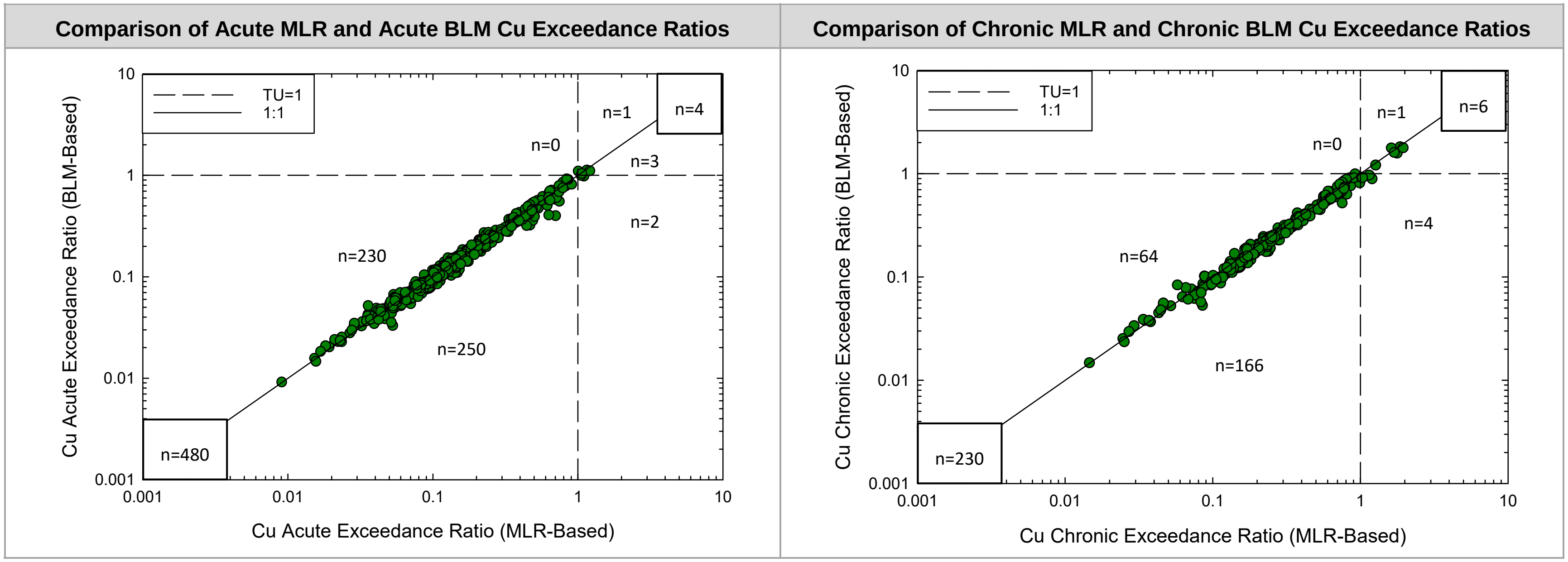
Figure 5-6. Comparison of BLM- and MLR-based acute criteria

Figure 5-6 shows how the MLR- and BLM-based copper WQC vary as a function of DOC (top row), pH (middle row), and hardness (bottom row). For comparative purposes, MLR- and BLM-based copper WQC were generated using various combinations of DOC, pH, and hardness concentrations corresponding to the 10th, 50th, and 90th percentiles in the BLM dataset for the Pajarito Plateau (shown as the colored lines and panels A, B, and C in Figure 5-6). This comparison further demonstrates the consistency between MLR-based copper WQC (solid lines, triangles) and BLM-based copper WQC (dashed lines, open circles) across a wide range of water chemistries. The greatest deviation between the two approaches occurs at high-hardness concentrations (≥ 200 mg/L); however, BLM-based copper WQC are greater than MLR-based copper WQC, indicating that the proposed MLR-based copper WQC are conservative under high-hardness conditions. Furthermore, such conditions are uncommon in surface waters on the Pajarito Plateau, as indicated by the 5th and 95th percentiles shown on the x-axes in Figure 5-6. Overall, the high degree of consistency between BLM- and MLR-based WQC over the range of water chemistries observed throughout the Pajarito Plateau indicates that the proposed MLR equations provide a reliable and scientifically defensible method to accurately estimate EPA's (2007a) nationally recommended copper WQC on a site-specific basis. Appendix B provides additional evaluations of the proposed MLR equations that further substantiate their selection as proposed copper SSWQC.

5.5 Comparison to Current Copper WQC

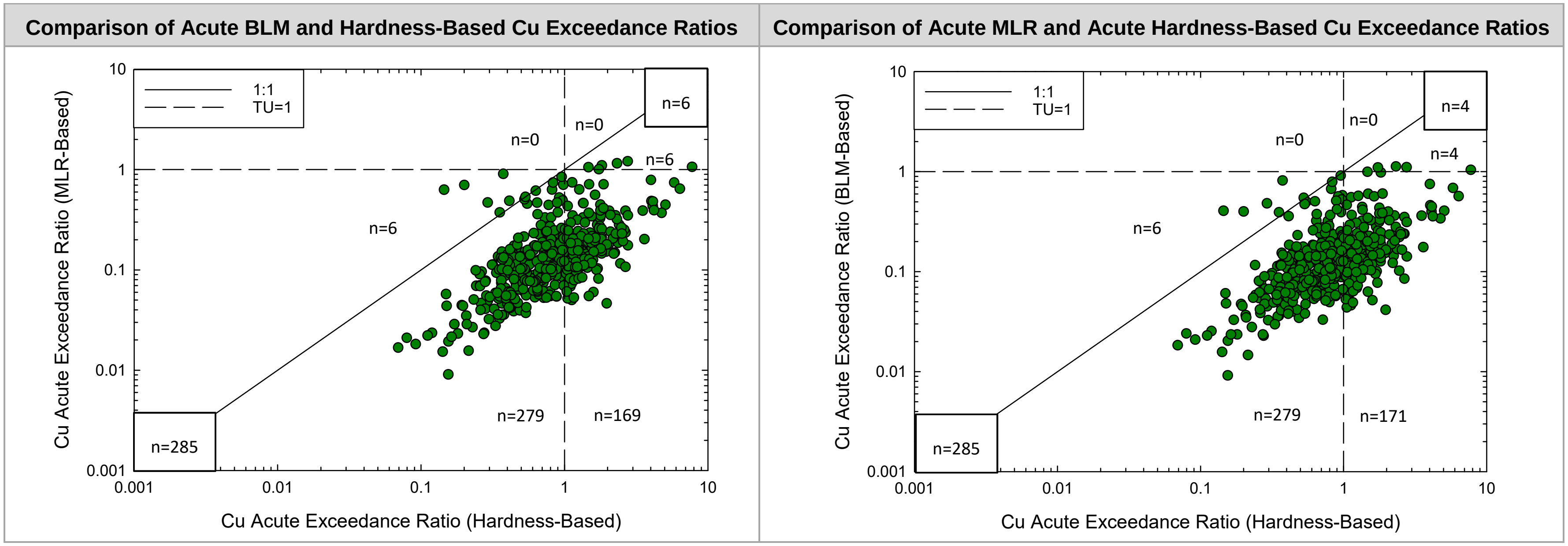
Comparisons of copper exceedance ratios[18] calculated using EPA's (2007a) BLM, the site-specific MLR (Equation 1), and New Mexico's current hardness-based WQC are shown in Figures 5-7 through 5-10. Figure 5-7 compares exceedance ratios for the acute and chronic BLM- and MLR-based criteria. Figure 5-8a compares acute exceedance ratios for the BLM- and MLR-based criteria to acute hardness-based criteria, and Figure 5-8b presents the same comparison for exceedance ratios of the analogous chronic criteria. Figures 5-9 and 5-10 present similar results as boxplots (showing results by watershed) for the acute and chronic criteria, respectively.

[18] Exceedance ratio = measured copper concentration divided by copper WQC.



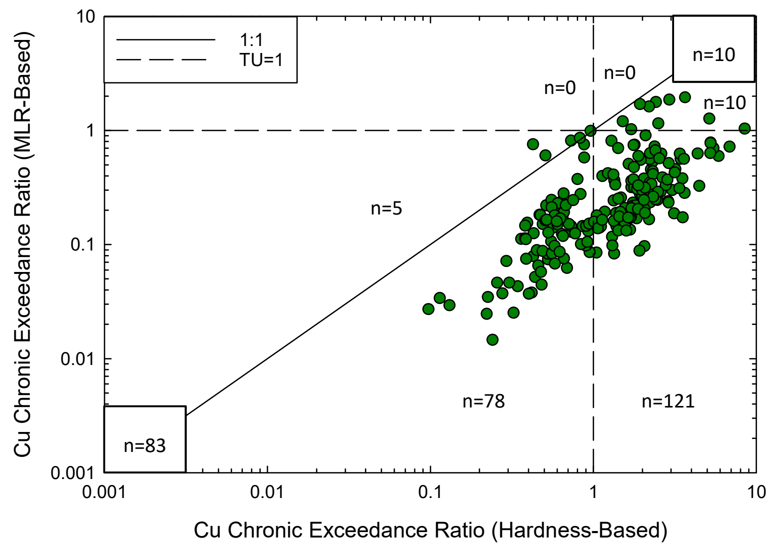
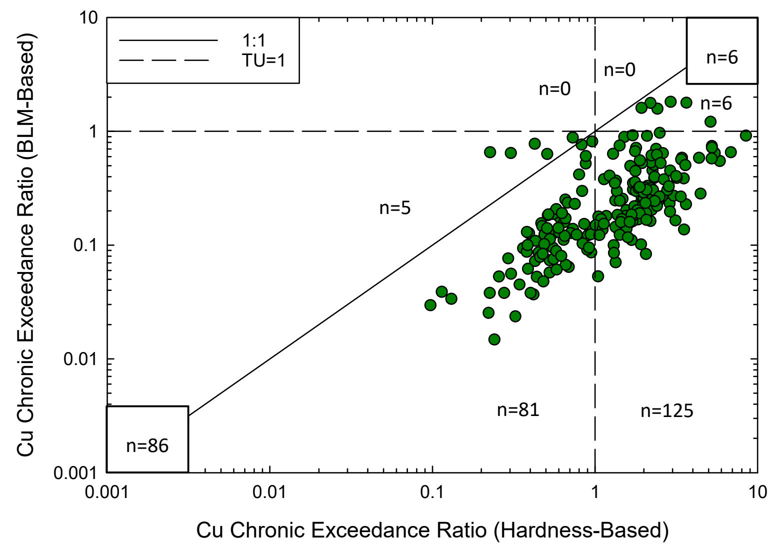
Note: Copper exceedance ratios are measured dissolved copper concentrations divided by a copper criterion. The solid 1:1 line represents perfect agreement between two criteria, and the dashed lines indicate the points at which copper concentrations exceed each criterion. “N” sample sizes represent the counts of samples in subareas of the plot defined by the solid and dashed lines. The “N” values in boxes represent the sums of samples in either the upper right or lower left quadrant, where there is general agreement between the two criteria (i.e., both predict an exceedance or non-exceedance of a copper criterion). The chronic exceedance ratio plot on the right excludes samples collected from locations classified under 20.6.4.128 NMAC in which only the acute criteria apply. Plots exclude samples in the Pajarito Plateau BLM dataset where copper detection limits were greater than BLM calculations.

Figure 5-7. Comparison of copper exceedance ratios between EPA (2007) BLM WQC and site-specific MLR WQC



Note: Copper exceedance ratios are measured dissolved copper concentrations divided by a copper criterion. The solid 1:1 line represents perfect agreement between two criteria, and the dashed lines indicate the points at which copper concentrations exceed each criterion. "N" sample sizes represent the count of samples in subareas of the plot defined by the solid and dashed lines. The "N" values in boxes represent the sums of samples in either the upper right or lower left quadrant, where there is general agreement between the two criteria (i.e., both predict an exceedance or non-exceedance of a copper criterion). Plots exclude samples in the Pajarito Plateau BLM dataset, where copper detection limits were greater than BLM-based or hardness-based WQC.

Figure 5-8a. Comparison of acute copper exceedance ratios between site-specific copper MLR WQC and New Mexico hardness-based WQC, and between EPA (2007) BLM calculations and New Mexico hardness-based WQC

Comparison of Chronic BLM to Chronic Hardness-Based Exceedance Ratios	Comparison of Chronic MLR to Chronic Hardness-Based Exceedance Ratios
	

Note: Copper exceedance ratios are measured dissolved copper concentrations divided by a copper criterion. The solid 1:1 line represents perfect agreement between two criteria, and the dashed lines indicate the points at which copper concentrations exceed each criterion. “N” sample sizes represent the count of samples in subareas of the plot defined by the solid and dashed lines. The “N” values in boxes represent the sums of samples in either the upper right or lower left quadrant, where there is general agreement between the two criteria (i.e., both predict an exceedance or non-exceedance of a copper criterion). Plots exclude samples in the Pajarito Plateau BLM dataset, where copper detection limits were greater than BLM-based or hardness-based WQC and samples collected from locations classified under 20.6.4.128 NMAC in which acute only criteria applies.

Figure 5-8b. Comparison of chronic copper exceedance ratios between site-specific copper MLR WQC and New Mexico hardness-based WQC, and between EPA (2007) BLM calculations and New Mexico hardness-based WQC

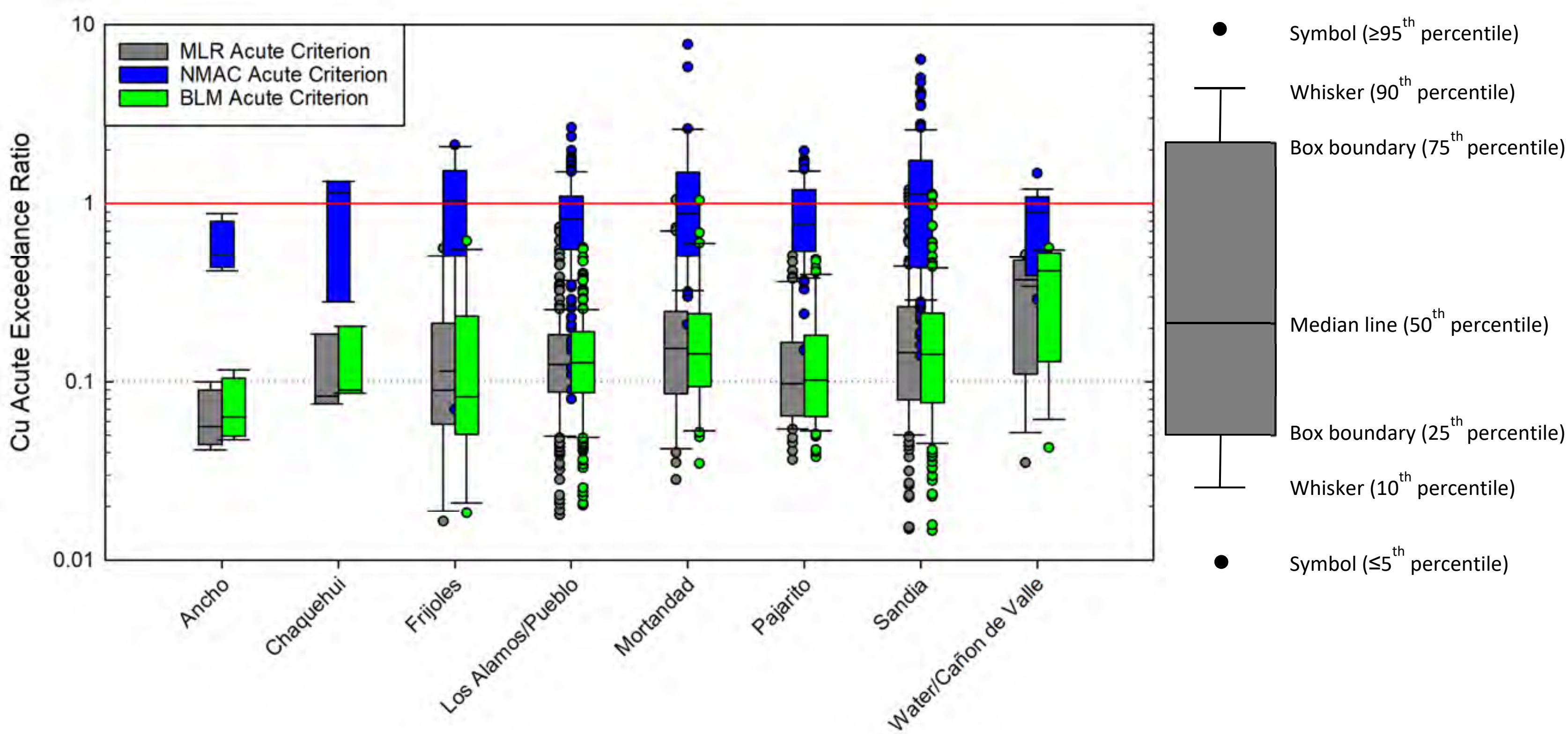


Figure 5-9. Acute copper exceedance ratios for EPA (2007) BLM, site-specific MLR, and New Mexico hardness-based WQC for major watersheds on the Pajarito Plateau

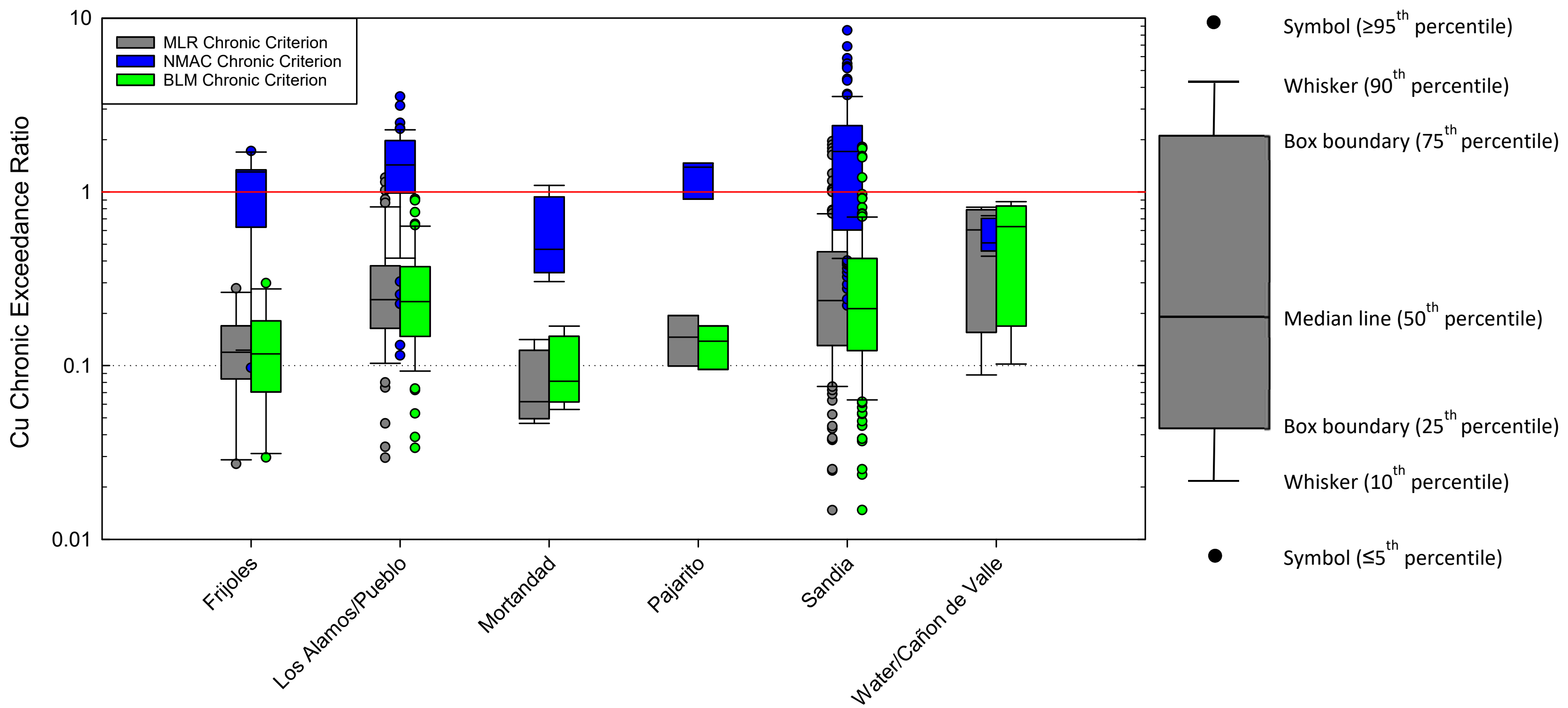


Figure 5-10. Chronic copper exceedance ratios for EPA (2007) BLM, site-specific MLR, and New Mexico hardness-based WQC for major watersheds on the Pajarito Plateau

Several conclusions can be drawn based on these comparisons. First, the frequency and magnitude with which copper concentrations exceed either BLM- or MLR-based acute WQC are very similar. For example, four exceedances of the acute BLM WQC and six exceedances of the acute MLR WQC and six exceedances of the chronic BLM WQC and 10 exceedances of the chronic MLR WQC were observed in the final DQO dataset (i.e., points above the horizontal dashed line or right of the vertical dashed line, respectively, in Figure 5-7).[19] The magnitude of these exceedances was low (i.e., acute exceedance ratios < 1.2 and chronic exceedance ratios < 2.0 for both models). Figure 5-7 also shows that exceedance ratios are highly correlated and distributed evenly around the solid diagonal 1:1 line (representing perfect agreement), again reflecting the high accuracy with which the MLR equations generate BLM software-based criteria.

Differences in exceedance frequencies between hardness-based WQC and BLM- or MLR-based WQC were substantial (e.g., n = 175 points to the right of the vertical dashed lines in Figure 5-8a and n = 131 points to the right of the vertical dashed lines in Figure 5-8b). Spatially, these hardness-based WQC exceedances occurred across most of the major Pajarito Plateau watersheds (Figure 5-9).

Finally, the differences observed between the hardness-based exceedance ratios and those calculated using either the BLM or MLR reflect the strong influence of water chemistry parameters other than hardness (e.g., pH and DOC) on the bioavailability and toxicity of copper. Consequently, continued application of the current hardness-based copper WQC is likely to lead to inaccurate and unnecessary regulatory actions (e.g., 303[d] listings and TMDLs), given that the MLR-based copper WQC are based on the best available science and provide a more accurate level of protection in accordance with EPA (1985, 2007a) recommendations.

5.6 CONSIDERATION OF DOWNSTREAM RIO GRANDE WATERS

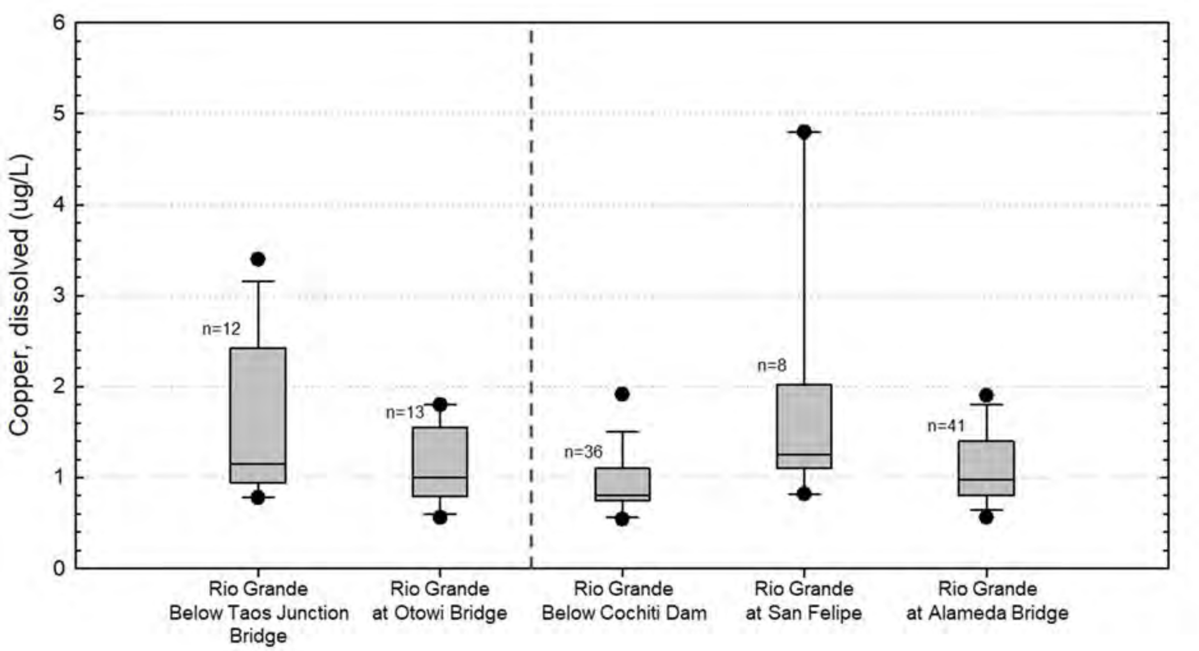
The SSWQC proposed in this report would apply to waters flowing into the Rio Grande from the Pajarito Plateau but not to waters of the Rio Grande. Potential impacts of the SSWQC on downstream waters in the Rio Grande were evaluated and found to be absent.

Rio Grande water quality data collected by the United States Geological Survey (USGS) were obtained from the National Water Quality Monitoring Council (2019) and were then input into the copper SSWQC equations and New Mexico's hardness-based copper criteria equations. Figure 5-11 shows available copper concentrations measured at USGS gaging stations on the Rio Grande from 2005 to 2021.[20] Copper concentrations in the Rio Grande upstream and downstream of confluences with

[19] Figures 5-7 to 5-9 exclude samples with non-detect copper concentrations exceeding the BLM copper WQC.

[20] Rio Grande data used for this evaluation are also presented in Appendix D (Table D-1).

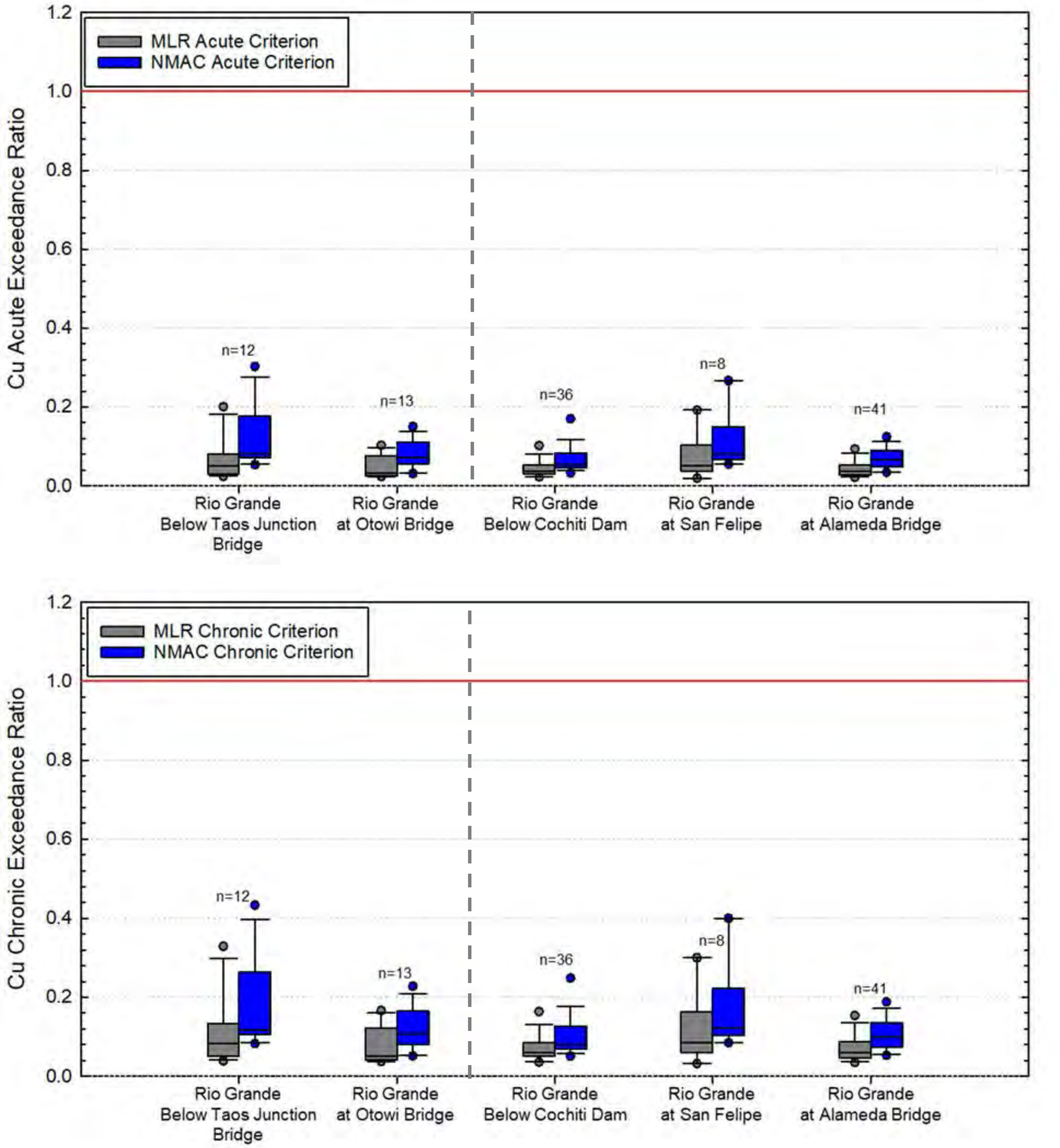
Pajarito Plateau tributaries are low and stable, and no samples contained copper concentrations in excess of either the hardness-based criteria or the BLM-based SSWQC (Figure 5-12). This finding is also consistent with the lack of 303(d) listings for copper in the Rio Grande in the vicinity (upstream and downstream) of the Laboratory. The two AUs of the Rio Grande above and three AUs below confluences with Pajarito Plateau tributaries have not been listed as impaired due to copper in New Mexico's 303(d)/305(b) IRs available on NMED's webpage (NMED 2021), which includes listings for the 2008-2010 IR through the draft 2022-2024 IR cycles. It is also notable that copper concentrations in the Rio Grande are comparable to or less than copper background threshold values (BTVs) derived for undeveloped conditions on the Pajarito Plateau (3.12 µg/L) and substantially less than BTVs for developed conditions (urban runoff) unrelated to LANL (9.03 µg/L) (Windward 2020).



Source: National Water Quality Monitoring Council (2019)

Note: The vertical dashed line indicates the division between locations that are upstream of confluences draining from the Pajarito Plateau (left of line) and those that are downstream (right of line).

Figure 5-11. Dissolved copper concentrations in Rio Grande surface water



Note: The vertical dashed line indicates the division between locations that are upstream of confluences draining from the Pajarito Plateau (left of line) and those that are downstream (right of line). The red line is the threshold above which copper exceeds the associated criterion.

Figure 5-12. Copper WQC exceedance ratios for Rio Grande surface waters

As discussed in Section 2.2, the proposed copper SSWQC do not entail new activities, such as new discharges or sources of copper, that could potentially lead to an increase in copper loads to the Rio Grande. In addition, surface flows from the Pajarito Plateau rarely reach the Rio Grande due to limited flow durations and infiltration in the canyon reaches upgradient of the Rio Grande (Section 3.3). Based on these considerations, adoption of the SSWQC is expected to remain protective of aquatic life uses in the Rio Grande.

6 Conclusions and Recommended Copper SSWQC

Over the past 40 years, the scientific understanding of metal toxicity and bioavailability to aquatic organisms and the corresponding environmental regulations have increased. EPA has revised nationally recommended copper WQC from a simple linear equation based on hardness to a mechanistic model (the copper BLM) that more accurately accounts for the modifying effect of site-specific water chemistry. Accordingly, BLM inputs and outputs were used to develop MLR equations proposed as copper SSWQC for surface waters of the Pajarito Plateau.

Streams on the Pajarito Plateau are thoroughly monitored under a variety of EPA and NMED programs, so it is a suitable setting for developing BLM-based WQC. Using a site-specific dataset generated from long-term monitoring, the current evaluation demonstrates that pH, DOC, and hardness concentrations account for 98% of the variation in BLM WQC. Therefore, the copper BLM can be estimated using a three-parameter MLR equation without losing significant accuracy, and while retaining the scientific rigor afforded by the BLM.

Given the high degree of agreement between the acute and chronic MLRs and the BLM, the equations presented in Section 6.1 can be adopted as copper SSWQC. They will provide accurate criteria that are protective of aquatic life in surface waters of the Pajarito Plateau, consistent with EPA recommendations and New Mexico WQS (20.6.4.10 NMAC).

6.1 Proposed Copper SSWQC Equations and Applicability

MLR equations were developed for both acute and chronic copper SSWQC for application to surface waters of the Pajarito Plateau. The use of one or both of the SSWQC depends on the hydrologic classification of the waterbody, as described below.

The proposed acute SSWQC is as follows:

$$\boldsymbol{SSWQC_{acute} = exp(-22.914 + 1.017 \times ln(DOC) + 0.045 \times ln(hardness) + 5.176 \times pH - 0.261 \times pH^2)}$$

The proposed chronic SSWQC is as follows:

$$\boldsymbol{SSWQC_{chronic} = exp(-23.391 + 1.017 \times ln(DOC) + 0.045 \times ln(hardness) + 5.176 \times pH - 0.261 \times pH^2)}$$

As described in Section 3.3, the Pajarito Plateau has ephemeral, intermittent, and perennial surface waters. Hydrologic classifications did not influence the ability of the proposed acute and chronic SSWQC to accurately estimate BLM calculations. Therefore, the acute and chronic copper SSWQC equations can be applied to any water body on the Pajarito Plateau.

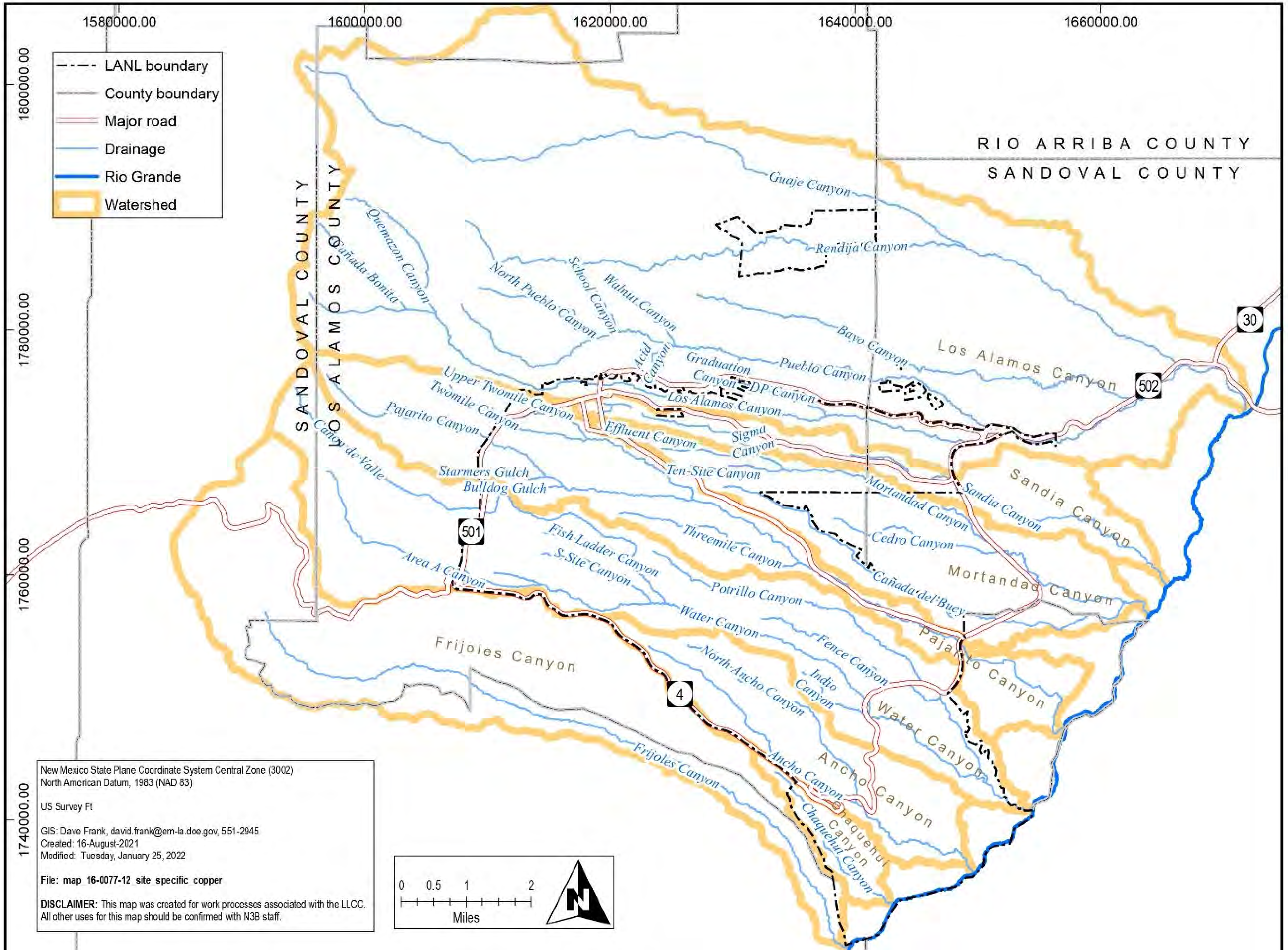
Most water bodies within the Laboratory's vicinity are classified as ephemeral or intermittent (20.6.4.128 NMAC); they are therefore designated as providing a limited aquatic life use and are subject to acute WQC only. Thus, the acute SSWQC equation would apply to those waters.

Other water bodies in the area are classified as perennial (20.6.4.126 and 20.6.4.121 NMAC) and are designated as providing higher-level aquatic life uses; these water bodies are subject to both acute and chronic aquatic life WQC. Unclassified surface water segments (20.6.4.98 NMAC) are designated as providing a marginal warm water aquatic life use and are subject to both acute and chronic WQC. Both the acute and chronic equations would apply to perennial and unclassified waters of the Pajarito Plateau.

As discussed in Section 2.4, the copper SSWQC are intended for eventual use in NPDES permits applicable to surface waters of the Pajarito Plateau. If the proposed copper SSWQC are adopted into New Mexico's WQS, updated TALs, benchmarks, and water quality-based effluent limits would be developed in accordance with each permitting program using the SSWQC criteria equations and appropriate datasets.

6.2 Spatial Boundaries for Proposed SSWQC

The spatial boundaries for the proposed SSWQC include all watersheds within the area of the Pajarito Plateau, from the Guaje Canyon watershed in the north to El Rito de Frijoles watershed in the south, from their headwaters to their confluence with the Rio Grande (Map 6-1). This area includes tributary streams and ephemeral or intermittent waters, regardless of whether they have a direct confluence with the Rio Grande or sufficient flow to reach the Rio Grande under normal conditions. Table 6-1 presents all AUs included in this area, their current classifications under NMAC, and their associated designated uses. The applicability of the acute and chronic SSWQC are also provided.



Map 6-1. Spatial boundary for proposed copper SSWQC

Table 6-1. Pajarito Plateau AUs Where SSWQC Would Apply

AU ID	Major Watershed	AU Name	Stream Type	NMAC Class	Designated Use*							
					SSWQC Applicability	AL	Irr.	LW	WH	DW	PC	SC
NM-9000.A_054	Ancho	Ancho Canyon (Rio Grande to North Fork Ancho)	ephemeral	128	acute only	X		X	X			X
NM-9000.A_055	Ancho	North Fork Ancho Canyon (Ancho Canyon to headwaters)	ephemeral	128	acute only	X		X	X			X
NM-9000.A_046	Chaquehui	Ancho Canyon (North Fork to headwaters)	ephemeral	128	acute only	X		X	X			X
NM-128.A_03	Chaquehui	Chaquehui Canyon (within LANL)	ephemeral	128	acute only	X		X	X			X
NM-9000.A_005	Chupaderos	Guaje Canyon (San Ildefonso bnd to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-2118.A_70	Frijoles	Rito de los Frijoles (Rio Grande to headwaters)	perennial	121	acute and chronic	X	X	X	X	X	X	
NM-126.A_03	Frijoles	Water Canyon (Area-A Canyon to NM 501)	perennial	126	acute and chronic	X	X	X	X			X
NM-97.A_002	Los Alamos/Pueblo	Acid Canyon (Pueblo Canyon to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-97.A_007	Los Alamos/Pueblo	Bayo Canyon (San Ildefonso bnd to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-128.A_14	Los Alamos/Pueblo	DP Canyon (Grade control to upper LANL bnd)	ephemeral	128	acute only	X		X	X			X
NM-128.A_10	Los Alamos/Pueblo	DP Canyon (Los Alamos Canyon to grade control)	intermittent	128	acute only	X		X	X			X
NM-97.A_005	Los Alamos/Pueblo	Graduation Canyon (Pueblo Canyon to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-97.A_003	Los Alamos/Pueblo	Kwage Canyon (Pueblo Canyon to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-9000.A_063	Los Alamos/Pueblo	Los Alamos Canyon (DP Canyon to upper LANL bnd)	ephemeral	128	acute only	X		X	X			X
NM-127.A_00	Los Alamos/Pueblo	Los Alamos Canyon (Los Alamos Rsvr to headwaters)	perennial	127	acute and chronic	X	X	X	X		X	
NM-9000.A_006	Los Alamos/Pueblo	Los Alamos Canyon (NM-4 to DP Canyon)	ephemeral	128	acute only	X		X	X			X
NM-9000.A_000	Los Alamos/Pueblo	Los Alamos Canyon (San Ildefonso bnd to NM-4)	intermittent	98	acute and chronic	X		X	X		X	
NM-9000.A_049	Los Alamos/Pueblo	Los Alamos Canyon (upper LANL bnd to Los Alamos Rsvr)	ephemeral	98	acute and chronic	X		X	X		X	

					Designated Use*							
AU ID	Major Watershed	AU Name	Stream Type	NMAC Class	SSWQC Applicability	AL	Irr.	LW	WH	DW	PC	SC
NM-9000.A_043	Los Alamos/Pueblo	Pueblo Canyon (Acid Canyon to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-99.A_001	Los Alamos/Pueblo	Pueblo Canyon (Los Alamos Canyon to Los Alamos WWTP)	ephemeral	98	acute and chronic	X		X	X		X	
NM-97.A_006	Los Alamos/Pueblo	Pueblo Canyon (Los Alamos WWTP to Acid Canyon)	ephemeral	98	acute and chronic	X		X	X		X	
NM-9000.A_045	Los Alamos/Pueblo	Rendija Canyon (Guaje Canyon to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-97.A_029	Los Alamos/Pueblo	South Fork Acid Canyon (Acid Canyon to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-97.A_004	Los Alamos/Pueblo	Walnut Canyon (Pueblo Canyon to headwaters)	ephemeral	98	acute and chronic	X		X	X		X	
NM-128.A_00	Mortandad	Canada del Buey (within LANL)	ephemeral	128	acute only	X		X	X			X
NM-128.A_17	Mortandad	Ten Site Canyon (Mortandad Canyon to headwaters)	ephemeral	128	acute only	X		X	X			X
NM-128.A_16	Pajarito	Arroyo de la Delfe (Pajarito Canyon to headwaters)	ephemeral	128	acute only	X		X	X			X
NM-126.A_01	Pajarito	Pajarito Canyon (Arroyo de La Delfe to Starmers Spring)	perennial	126	acute and chronic	X	X	X	X			X
NM-128.A_08	Pajarito	Pajarito Canyon (lower LANL bnd to Two Mile Canyon)	ephemeral	128	acute only	X		X	X			X
NM-9000.A_040	Pajarito	Pajarito Canyon (Rio Grande to LANL bnd)	ephemeral	98	acute and chronic	X		X	X		X	
NM-128.A_06	Pajarito	Pajarito Canyon (Two Mile Canyon to Arroyo de La Delfe)	intermittent	128	acute only	X		X	X			X
NM-9000.A_048	Pajarito	Pajarito Canyon (upper LANL bnd to headwaters)	intermittent	98	acute and chronic	X		X	X		X	
NM-128.A_07	Pajarito	Pajarito Canyon (within LANL above Starmers Gulch)	intermittent	128	acute only	X		X	X			X
NM-9000.A_091	Pajarito	Three Mile Canyon (Pajarito Canyon to headwaters)	ephemeral	128	acute only	X		X	X			X
NM-128.A_15	Pajarito	Two Mile Canyon (Pajarito to headwaters)	ephemeral	128	acute only	X		X	X			X
NM-9000.A_053	Rio Grande	Cañada del Buey (San Ildefonso Pueblo to LANL bnd)	ephemeral	98	acute and chronic	X		X	X		X	
NM-9000.A_042	Sandia	Mortandad Canyon (within LANL)	ephemeral	128	acute only	X		X	X			X

AU ID	Major Watershed	AU Name	Stream Type	NMAC Class	Designated Use*							
					SSWQC Applicability	AL	Irr.	LW	WH	DW	PC	SC
NM-9000.A_047	Sandia	Sandia Canyon (Sigma Canyon to NPDES outfall 001)	perennial	126	acute and chronic	X	X	X	X			X
NM-128.A_11	Sandia	Sandia Canyon (within LANL below Sigma Canyon)	ephemeral	128	acute only	X		X	X			X
NM-128.A_01	Water/Cañon de Valle	Canon de Valle (below LANL gage E256)	ephemeral	128	acute only	X		X	X			X
NM-126.A_00	Water/Cañon de Valle	Canon de Valle (LANL gage E256 to Burning Ground Spr)	perennial	126	acute and chronic	X	X	X	X			X
NM-9000.A_051	Water/Cañon de Valle	Canon de Valle (upper LANL bnd to headwaters)	intermittent	98	acute and chronic	X		X	X		X	
NM-128.A_02	Water/Cañon de Valle	Canon de Valle (within LANL above Burning Ground Spr)	ephemeral	128	acute only	X		X	X			X
NM-128.A_04	Water/Cañon de Valle	Fence Canyon (above Potrillo Canyon)	ephemeral	128	acute only	X		X	X			X
NM-128.A_05	Water/Cañon de Valle	Indio Canyon (above Water Canyon)	ephemeral	128	acute only	X		X	X			X
NM-128.A_09	Water/Cañon de Valle	Potrillo Canyon (above Water Canyon)	ephemeral	128	acute only	X		X	X			X
NM-9000.A_044	Water/Cañon de Valle	Water Canyon (Rio Grande to lower LANL bnd)	ephemeral	98	acute and chronic	X		X	X		X	
NM-9000.A_052	Water/Cañon de Valle	Water Canyon (upper LANL bnd to headwaters)	intermittent	98	acute and chronic	X		X	X		X	
NM-128.A_12	Water/Cañon de Valle	Water Canyon (within LANL above NM 501)	intermittent	128	acute only	X		X	X			X
NM-128.A_13	Water/Cañon de Valle	Water Canyon (within LANL below Area-A Cyn)	ephemeral	128	acute only	X		X	X			X

* AL – aquatic life; Irr. – irrigation; LW – livestock watering; WH – wildlife habitat; DW – drinking water; PC – primary contact; SC – secondary contact

AU – assessment unit

ID – identification

NMAC – New Mexico Administrative Code

SSWQC – site-specific water quality criteria

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Appendix A

BLM Dataset for Pajarito Plateau Surface Waters (on CD included with this document)

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APPENDIX B. SUPPLEMENTAL STATISTICAL ANALYSES

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Acronyms

AIC	Akaike's Information Criterion
BIC	Bayesian Information Criterion
BLM	biotic ligand model
DOC	dissolved organic carbon
DQA	data quality assessment
DQO	data quality objective
EIM	Environmental Information Management
EPA	US Environmental Protection Agency
LANL	Los Alamos National Laboratory
MLR	multiple linear regression
N3B	Newport News Nuclear BWXT-Los Alamos, LLC
NMAC	New Mexico Administrative Code
RCRA	Resource Conservation and Recovery Act
SSWQC	site-specific water quality criteria
TOC	total organic carbon
Windward	Windward Environmental LLC
WQS	water quality standards
WM	snowmelt (water sample type)
WP	persistent flow (water sample type)
WS	surface water (water sample type)
WT	storm water (water sample type)

B1 Overview

This appendix provides additional information on the development of copper site-specific water quality criteria (SSWQC) proposed for surface waters on the Pajarito Plateau, Los Alamos County, New Mexico. The general approach is discussed in the main text, but this appendix provides additional technical details. The approach involves developing multiple linear regressions (MLRs) that accurately predict US Environmental Protection Agency (EPA) (2007) copper biotic ligand model (BLM) criteria based on available site-specific water chemistry.

The remainder of this appendix is organized as follows:

- Section B2 – Data Aggregation
- Section B3 – Data Analysis Methods
- Section B4 – Model Evaluation
- Section B5 – Model Uncertainty
- Section B6 – Summary of MLR Development
- Section B7 – References

Section B2 provides a discussion of the aggregation of the Los Alamos National Laboratory's (LANL's) BLM data that were used to develop and evaluate MLRs. Section B3 provides a detailed discussion of the methods used to develop MLRs, and Section B4 presents the results of the development process. Section B5 provides a brief evaluation of dataset and model uncertainties not discussed in Sections B3 or B4, including a detailed evaluation of models using updated hydrology classifications based on recent hydrology protocol assessments by the New Mexico Environment Department (NMED) and Triad National Security. Section B6 summarizes the key results and conclusions from the development of MLRs. References cited in this appendix are presented in Section B7.

B2 Data Aggregation

This section describes the aggregation of BLM data for the development of MLRs. Aggregation involved the acquisition of source data, estimation of missing data to fill gaps, and cleanup and removal of data. Cleanup and removal of data occurred at different points during the aggregation process, as certain limitations of the dataset (with respect to BLM calculations and MLR development) were recognized.

B2.1 SOURCE DATA

The source dataset was generated by LANL/Newport News Nuclear BWXT-Los Alamos, LLC (N3B) and their contractors, uploaded to the Environmental Information Management (EIM) database, and then exported and provided to Windward Environmental LLC (Windward) by N3B. This occurred in two phases for data included in the 2018 data quality objective (DQO)/data quality assessment (DQA) report (Windward 2018) and for data collected through 2019. All data were reviewed and treated in a similar manner. The complete dataset (2005 to 2019) was compiled to provide all available EIM records for the following information:

- BLM analyte concentrations, starting with pH and dissolved organic carbon (DOC) pairs but including all parameters as available
- Secondary analytes that could aid in filling data gaps and further interpretation of the BLM dataset and outcomes (e.g., hardness and specific conductance)
- Water sample types, including surface water (WS), snowmelt (WM), persistent flow (WP), and storm water (WT)[1]
- Sampling location names, aliases, and coordinates
- Analytical quality control/validation flags
- Other sample information deemed to be of potential interest by N3B (e.g., sampling method and date, analytical method, sample preparation/filtration method, sampling program)

N3B also provided various other sample classifications not currently in EIM that could support SSWQC development. These classifications were generally produced through GIS analysis and field surveys conducted at the LANL property (hereinafter referred to as the Laboratory). These classifications included but were not limited to New Mexico Administrative Code (NMAC) stream hydrologic type, additional sample type classification (e.g., "stormwater runoff" versus "surface water"), land use, and historical wildfires. "Stormwater runoff" data were excluded from the development of the MLR, because the BLM is intended to apply to receiving water streams (including stormflow events), not to stormwater discharge or effluent.

[1] A subset of stormwater samples was excluded from the BLM dataset because these samples were not clearly associated with a surface water assessment unit. These samples were collected at or near a stormwater discharge point rather than in a stream channel during a stormflow event.

B2.2 AGGREGATION AND ADDRESSING DATA GAPS

Starting with the source dataset (n = 1,323 events), acceptable data were sequentially selected for use. Aggregation steps for BLM parameters (including steps wherein BLM parameters were estimated) were as follows:

1) Process used measured concentrations of each parameter from filtered samples for each event, if available.
2) When measured, filtered concentrations were not available for pH and alkalinity, so unfiltered sample results from the same event were used. Unfiltered alkalinity was shown by Windward (2018) to be comparable to filtered alkalinity in paired samples. The measurement of pH is almost always measured in unfiltered samples.
3) To fill gaps in the dataset, DOC was estimated from total organic carbon (TOC) for a subset of samples by applying a conversion factor, discussed later in this section.
4) If measured concentrations were unavailable from both filtered and unfiltered samples, some BLM input parameters were estimated from another water chemistry characteristic; for example, hardness was calculated from calcium and magnesium.[2]
5) For samples with BLM inputs that could not be estimated reasonably from another water chemistry characteristic (i.e., measured in neither filtered nor unfiltered samples), an average concentration was used for the location (using concentrations from other samples from the same location). This approach applied only to sulfate and chloride.
6) If no data were available for a BLM input, then either a default value from the BLM guidance was applied (e.g., 10% humic acid), or a sensitivity analysis was performed to identify a static input value leading to a conservative BLM output. The sensitivity analysis step applied to temperature only and had been carried out previously by Windward (2018).

Non-detected analytical results were replaced by one-half the detection limit. This approach was used because statistical approaches (e.g., Kaplan-Meier method, maximum likelihood estimation, or regression on order statistics) are not appropriate for predicting single concentrations.[3]

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[2] A standard equation for calculating total hardness in mg/L calcium carbonate was used: hardness = 2.5 × calcium + 4.1 × magnesium.

[3] Rather, non-detect estimation methods such as the Kaplan-Meier method are appropriate for estimating summary statistic parameters like the mean and confidence limits.

Consistent with the 2018 DQO/DQA evaluation, a conservative temperature of 10°C was applied to all samples when running the BLM (Windward 2018). This is the lower bound of the BLM's prescribed range for temperature (Windward 2019), and temperature is known to have little if any effect on BLM output. Humic acid was set to 10% for all samples, consistent with guidance (Windward 2019). Sulfide was set equal to the lower bound of the BLM's prescribed range, 1×10^{-3} mg/L (Windward 2019).

As described by EPA (2007), the proportion of organic carbon expected to be dissolved can be estimated based on relationships between paired measures of DOC and TOC. Because the estimation of DOC from TOC was necessary for 124 samples in which only TOC was measured, a comparison of paired measures of DOC and TOC for surface water samples from the Pajarito Plateau was performed. Various approaches were used to compare DOC and TOC, including regression and ratio-based approaches (carried out using R software) (R Core Team 2020). Linear, log-linear, and quantile (median) regression methods were applied to the DOC and TOC data, and outliers were identified and removed based on large model residuals (i.e., prediction error) or influence (quantified using Cook's distance metric and screened against a metric threshold of 0.5). Additionally, mean and median DOC-to-TOC ratios were calculated as a relatively simple approach, consistent with EPA (2007) recommendations. EPA (2007) also provides default nationwide and state-specific conversion factors; these were used as a basis for comparison and confirmation of the calculated, site-specific conversion factor.

Regardless of the method used, there were concerns with the underlying DOC and TOC data for the specific purpose of predicting DOC from TOC,[4] because the mean and median DOC-to-TOC ratios exceeded one; more than one-half of the available DOC data exceeded TOC in paired samples. While it is theoretically not possible for DOC to exceed TOC, the data seeming to contradict this theory came from the standard sampling and analytical protocols used at LANL for DOC and TOC. Specifically, LANL measures organic carbon in filtered (DOC) and unfiltered (TOC) samples, which come from separate aliquots of a sample and possibly from separate sample bottles filled during the same event. This approach allows for variability and uncertainty inherent to the analytical instrument, sampling method, sample preparation (e.g., filtration), etc., all of which can result in DOC appearing to exceed TOC. To address this uncertainty in a conservative way, samples were considered only when DOC was less than or equal to TOC.[5]

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[4] The data used for this purpose were collected and analyzed using standard methods, and the resulting concentrations were validated by an independent party; therefore, the data are considered to be of high quality in general and so were not discarded from the dataset.

[5] This limitation on the dataset only applied to the calculation of a DOC-to-TOC conversion faction, not to the entire MLR development process.

The median DOC-to-TOC ratio of 0.859 was used as the final conversion factor. This value is virtually identical to the conversion factor used by Windward (2018) (0.86) and the national average presented by EPA (2007) (0.857) for streams; it is also similar to the value (0.83) used by the Oregon Department of Environmental Quality in its copper BLM-based WQC implementation guidance (Oregon DEQ 2016), as well as the New Mexico state-specific factor from EPA (2007) (0.815). The median ratio was also comparable to the model slopes from the linear, log-linear, and quantile regression approaches (after removing outliers but not excluding values wherein DOC exceeded TOC). Therefore, it provides reasonable and defensible estimates of DOC in Pajarito Plateau waters for the subset of samples in which DOC was estimated from TOC. Section B5.2.4 provides additional discussion of the influence of DOC on MLR development.

After working through the above steps, the following numbers of samples were sequentially aggregated:

- Among the 1,323 initial location-date sample pairings in the BLM dataset, there were 10 instances in which pH, DOC, and alkalinity were all measured in filtered samples. These samples were retained.
- A total of 479 samples were retained after adding 469 samples with pH and alkalinity from unfiltered samples.[6]
- A total of 606 samples were retained after adding 127 samples with representations or estimates of DOC.
    - Three filtered samples in which TOC was reported and therefore assumed to be DOC (incorrectly reported in EIM)
    - 124 samples for which DOC was estimated from TOC
- A total of 611 events were retained after inputting major anion data for 5 events.
    - Four samples lacked sulfate concentrations, so they were estimated using location-specific averages.
    - One sample lacked a chloride concentration, so it was estimated using a location-specific average.

B2.3 DATA CLEANUP

At the conclusion of the data aggregation steps described in Section B2.2, 611 samples had been retained. Data reduction steps were then taken to limit the dataset to BLM-relevant samples. First, any duplicated sample entries in EIM (of which four were observed) were reduced to a single unique sample. Then, all "stormwater discharge"

[6] Alkalinity from unfiltered samples was used as a substitute for missing dissolved alkalinity inputs. This was consistent with the 2018 DQO approach, which determined that unfiltered and filtered alkalinity values were comparable (when both values were reported for a single sample).

samples were excluded, leaving only surface water samples (including many "WT" stormflow samples). Lastly, any samples with pH, DOC, or hardness values falling outside the BLM's prescribed ranges (Table 5-2 of the main text) were excluded. After data cleanup, the result was a modeling dataset with 517 samples.

B2.4 FINAL DATASET

Table B1 shows a tabular breakdown of the 517 samples used for MLR development by major watershed and current NMAC hydrologic classification.[7]

Table B1 New Mexico WQS hydrologic classification assignments for the BLM dataset by major watershed

Major Watershed	NMAC Hydrological Classification			N by Watershed
	Ephemeral/ Intermittent (128)	Default Intermittent (98)	Perennial (121/126)	
Ancho	4	0	0	4
Chaquehui	3	0	0	3
Frijoles	0	9	8	17
Jemez River	0	6	0	6
Los Alamos/Pueblo	140	61	0	201
Mortandad	28	2	0	30
Pajarito	62	0	3	65
Sandia	8	0	148	156
Water/Cañon de Valle	4	12	19	35
N by Hydrology Class	**249**	**90**	**178**	**517**

BLM – biotic ligand model
NMAC – New Mexico Administrative Code
N – sample size
WQS – water quality standards

Appendix A provides the final dataset of BLM data, including the 517 samples used to develop MLRs and the 14 samples removed during the final data filtering step. The exclusion of data outside the prescribed BLM range (for pH, DOC, and hardness) was intended to avoid extrapolation of the BLM; however, BLM guidance suggests that removing such data is not necessary (Windward 2019). Therefore, the 14 samples removed during the last filtering step are included in Appendix A to facilitate future modeling efforts, which may include BLM data outside the prescribed ranges. Thus, the dataset provided in Appendix A includes 531 samples with all data needed to run the copper BLM.

[7] Figure 3-1 and Map 3-1 in the main text provide additional spatial context for the BLM dataset.

B2.5 ADDITIONAL DATA CONSIDERATIONS

Although land use can have an effect on downgradient water quality, there is no need to separate these data when developing or evaluating an MLR, if it can be demonstrated the MLR equation responds as well as the BLM software does to changes in water quality. This is discussed further in Section B5.2. Evaluations of samples potentially affected by historical fires showed BLM WQC and MLR-predicted WQC similar to those of unaffected samples; this is discussed in Section B5.3. Therefore, data potentially affected by different land uses and/or historical fires were not treated differently from other data when developing MLRs.

Hydrology was investigated in detail when developing the MLR (Sections B3 and B4), because of the various water types on the Pajarito Plateau (i.e., ephemeral, intermittent, and perennial). According to New Mexico water quality standards (WQSs), stream hydrology determines whether acute only or both acute and chronic WQC apply, so the proposed acute and chronic SSWQC, if adopted, would apply similarly.[8] For the purposes of developing and testing MLRs, existing NMAC hydrologic classifications for LANL waters were used (Section B4); however, Section B5.4 also details the investigation of proposed classifications from the most recent hydrology protocol efforts by NMED and the Laboratory. These updated classifications have not yet been approved, but they represent reasonable changes to previously unclassified (20.6.4.98 NMAC) waters based on standard methods.

B3 Data Analysis Methods

The final BLM dataset was evaluated iteratively to select the final MLR equation that accurately and most precisely predicted the BLM WQC. To arrive at a parsimonious model, the process considered the effects of continuous water quality variables, hydrological classification, and the possible influences of other sampling location characteristics not included in the model. Analyses were conducted using a series of well-accepted statistical methods (including common graphical evaluations), all of which were carried out in the R statistical environment (R Core Team 2020).

B3.1 INITIAL MODEL

An initial log-log linear MLR was developed and tested that included the parameters pH, DOC, and hardness. DOC and hardness were transformed using the natural log, whereas pH, already reported as a log-unit, was input to the model as-is. The structure of the initial model (Model 1) formed the basis for comparisons of models described in Section B3.2.

[8] Acute WQC apply in ephemeral and intermittent streams, whereas acute and chronic WQC apply in perennial and unclassified streams.

$$\ln(BLM) = intercept + \ln(DOC) + \ln(hardness) + pH \quad \textbf{Model 1}$$

Where:

BLM = calculated BLM-based WQC

ln = the natural logarithm

B3.2 Hydrologic Classification-specific Models

To address potential differences in model performance (or bias) among NMAC hydrologic classifications, these classifications were added to MLRs in different ways and tested over several rounds. The first round of analyses evaluated the precision and goodness of fit of a "full" model (Model 2)[9] that included the main categorical and continuous variables assumed to be important for predicting the BLM WQC. Three continuous water quality variables—DOC, hardness, and pH—were selected *a priori* to incorporate primary mechanisms that underpin the copper BLM (EPA 2007; Brix et al. 2017). Model 2 also included NMAC hydrological classifications (i.e., ephemeral/intermittent, intermittent, or perennial) as a categorical term, which introduced classification-specific slopes (for each of the continuous variables) and intercepts.

$$\ln(BLM) = HC_{int} + HC_{slope\_DOC} * \ln(DOC) + HC_{slope\_hardness} * \ln(hardness) + HC_{slope\_pH} * pH$$

Model 2

Where:

HC_{int} = hydrologic classification-specific intercept

HC_{slope} = hydrologic classification-specific and continuous variable-specific slope

Stepwise regression procedures based on the Akaike's and Bayesian Information Criteria (AIC and BIC) were used to determine whether the hydrology-specific slopes and/or intercepts provided statistically important contributions to the prediction of BLM WQC.[10] In other words, it was determined whether or not slopes and/or intercepts for DOC, hardness, and pH differed statistically among hydrologic classifications and how important those slopes and intercepts were for predicting the BLM WQC. When running the stepwise regression algorithm, the computational output describes the best-fitting equation, which contains only those parameters that

[9] In this appendix, the terms "Model" and "Equation" are used in different ways. They are distinguished as the general structure of the equation (model) versus the equation with specified coefficient values (equation).

[10] To control model complexity, the AIC and BIC reduce (penalize) the measure of model fit based on the number of parameters in the model. The BIC also penalizes the fit based on sample size. Above a certain sample size, AIC tends to result in larger models (i.e., retain more model terms), whereas BIC tends to generate smaller models with fewer terms.

significantly improve BLM WQC predictions. The final list of AIC or BIC model parameters is always a subset of the full model, potentially including all of the parameters in the full model.

The full model (including all hydrologic class-specific slopes and intercepts) was compared to the best-fitting models generated by each stepwise procedure using a number of statistics and visual tools. These tools described each model's goodness-of-fit (of predicted WQC to calculated WQC values) and the extent to which model residuals[11] met the assumptions of the linear modeling framework. The summary statistics reported include:

- Adjusted R^2 – fraction of variance in the BLM WQC explained by the MLR, penalized for the number of variables in the model
- Predicted R^2 – ability of MLR to predict out-of-sample BLM WQC and therefore a measure of how well the model might predict future WQC; also describes model's reliance on single data points, with low predicted R^2 suggesting that model has too many parameters
- AIC and BIC – measures of model fit, with lower values indicating better fit
- Shapiro-Wilk test – indicates whether residuals are normally distributed (assumption of MLR), with $p < 0.05$ suggesting non-normality
- Scores test – indicates whether residuals are homoscedastic (assumption of MLR), with $p < 0.05$ suggesting non-constant variance or heteroscedasticity

Standard diagnostic plotting methods of model residuals were evaluated, including plots to assess normality, homogeneity of variance, and relationships between residuals and independent continuous variables of the model (i.e., pH, DOC, and hardness).[12] Residual distributions were plotted by watershed and by hydrologic class to assess whether models were performing similarly across these categories.

In addition, the magnitudes of any statistically significant differences between hydrology-specific model terms were considered in terms of their impact on or relevance to ecological and regulatory issues. In other words, it was determined whether a significant difference was large enough to warrant an increase in MLR complexity. In addition to potentially impacting the predictive capability of the MLR for future data, increased complexity can make the model more difficult to use as a regulatory tool, for example, by requiring that the hydrological classification of a sampling location be known prior to applying the MLR.

[11] Model residuals = actual WQC – predicted WQC
[12] Default plots were generated in R using the plot.lm function.

Using the information about the importance of individual model terms provided by each line of investigation of model fit, the tradeoffs of simpler and more complex models were assessed, and a final set of models was recommended. The steps taken to refine the full model are described more completely in Section B4.

B4 Model Evaluations

This section provides the results of MLR development. Section B4.1 discusses the initial model (Model 1), and Section B4.2 discusses the hydrologic classification-specific models (Models 2 through 4) and the final model (Model 5).

B4.1 Initial Model Evaluation

Table B2 provides a summary of the initial model, Model 1. Evaluation of this model did not involve a stepwise regression step, since only the full model was considered. Subsequent models are discussed in Section B4.2. The model fit was strong even without added complexity (e.g., addition of hydrology classification factors), with an adjusted R^2 value of 0.969 and a predicted R^2 value of 0.968.

Table B2 Summary of MLR based on Model 1 structure

Model Parameter	Model Coefficient	Standard Error	Coefficient Significance (p-value)
Intercept	-8.21655	0.10778	<0.0001
DOC slope	1.00066	0.01039	<0.0001
Hardness slope	0.01166	0.01110	0.294
pH slope	1.27290	0.01625	<0.0001
Adjusted R^2	**0.969**		
Predicted R^2	**0.968**		

DOC – dissolved organic carbon

MLR – multiple linear regression

B4.2 Hydrologic Classification-specific Model Evaluation

The more complex Model 2 resulted in high adjusted and predicted R^2 values of 0.973 and 0.971, respectively (Table B3), although these values represented increases of only 0.004 and 0.003, respectively, relative to Model 1 (Table B2). The AIC and BIC models both resulted in the removal of hydrology-specific slopes for DOC and hardness but not pH.

Table B3 Summary of MLRs based on the Model 2 structure with comparison of full, AIC, and BIC models

Hydrologic Classification	Model Parameter	Model Coefficient		Coefficient Significance (p-value)[a]	
		Full	AIC/BIC Model	Full	AIC/BIC Model
Ephemeral/intermittent	intercept	-9.387119	-9.349237	<0.0001	<0.0001
Intermittent	intercept	-8.345361	-8.416672	0.000992	0.00178
Perennial	intercept	-7.324505	-7.340531	<0.0001	<0.0001
Ephemeral/intermittent	DOC slope	1.0182168	1.012158	<0.0001	<0.0001
Intermittent	DOC slope	1.0000358	na[b]	0.488	na[b]
Perennial	DOC slope	1.0211608	na[b]	0.899	na[b]
Ephemeral/intermittent	hardness slope	0.014166	0.032618	0.389	0.00231
Intermittent	hardness slope	0.050238	na[b]	0.206	na[b]
Perennial	hardness slope	0.039968	na[b]	0.297	na[b]
Ephemeral/intermittent	pH slope	1.425394	1.413439	<0.0001	<0.0001
Intermittent	pH slope	1.275228	1.289743	0.00133	0.00262
Perennial	pH slope	1.140642	1.148362	<0.0001	<0.0001
Adjusted R^2		**0.973**	**0.973**		
Predicted R^2		**0.971**	**0.971**		

[a] The significances of perennial and ephemeral coefficients represent differences from intermittent coefficients.

[b] AIC and BIC models excluded hydrology-specific coefficient; coefficient and p-value reported in table for ephemeral/intermittent applies to all samples.

AIC – Akaike's Information Criterion
BIC – Bayesian Information Criterion
DOC – dissolved organic carbon
MLR – multiple linear regression
na – not applicable

A clear curvilinear pattern emerged when comparing the residuals to pH (Figure 5-4 in the main text), suggesting a non-linear relationship between pH and the BLM WQC (when combined with hardness, DOC, and other parameters in an MLR). To address this, a new term was added in the model to eliminate the curvilinearity: When a squared pH term (pH^2) was added to the model formula (Model 3),[13] the adjusted R^2 increased from 0.973 to 0.984 (Table B4), and residuals became more normally distributed.

$$\ln(BLM) = HC_{int} + HC_{slope\_DOC}*\ln(DOC) + HC_{slope\_hardness}*\ln(hardness) + HC_{slope+pH}*pH + HC_{slope\_pH2}*pH^2$$

Model 3

[13] The implication of using a pH^2 term in the MLR is that, when DOC and hardness remain constant, the relationship between pH and the BLM WQC is parabolic (curved). In this case, pH exerts a smaller effect on the predicted WQC at the extremes of the pH range compared to the middle of the range.

Table B4 Summary of MLRs based on the Model 3 structure with comparison of full, AIC, and BIC models

Hydrologic Classification	Model Parameter	Model Coefficient		Coefficient Significance (p-value)[a]	
		Full and AIC	BIC	Full and AIC	BIC
Ephemeral/intermittent	intercept	-26.237	-26.728	<0.0001	<0.0001
Intermittent	intercept	-30.37868	-26.214669	0.187	<0.0001
Perennial	intercept	-25.882931	-26.742375	0.899	0.899
Ephemeral/intermittent	DOC slope	1.016194	1.032831	<0.0001	<0.0001
Intermittent	DOC slope	1.021582	na[b]	0.794	na[b]
Perennial	DOC slope	1.064993	na[b]	0.00849	na[b]
Ephemeral/intermittent	hardness slope	0.030987	0.052566	0.0180	<0.0001
Intermittent	hardness slope	0.080043	na[b]	0.0301	na[b]
Perennial	hardness slope	0.063531	na[b]	0.0967	na[b]
Ephemeral/intermittent	pH slope	6.089031	6.198747	<0.0001	<0.0001
Intermittent	pH slope	7.351267	na[b]	0.144	na[b]
Perennial	pH slope	5.959203	na[b]	0.865	na[b]
Ephemeral/intermittent	pH^2 slope	-0.323072	-0.330876	<0.0001	<0.0001
Intermittent	pH^2 slope	-0.420227	-0.33943	0.104	0.000152
Perennial	pH^2 slope	-0.314137	-0.328996	0.863	0.362
Adjusted R^2		**0.984**	**0.983**		
Predicted R^2		**0.981**	**0.981**		

[a] Significances of perennial and intermittent coefficients are differences from ephemeral/intermittent coefficients, whereas the significances of the ephemeral/intermittent coefficients are differences from zero.

[b] BIC model excluded hydrology-specific coefficient; coefficient and p-value reported in table for ephemeral/intermittent applies to all samples

AIC – Akaike's Information Criterion
BIC – Bayesian Information Criterion
DOC – dissolved organic carbon
MLR – multiple linear regression
na – not applicable

Although some hydrology-specific slopes and intercepts were retained by both the AIC and BIC stepwise procedures, the high adjusted R^2 and the relatively small differences among intercepts and slopes of the three hydrologic categories indicated that Model 3 could be simplified by removing the hydrology-specific slopes with little loss of information (Model 4). When hydrology-specific slopes were removed and a pH^2 term retained, Model 4 had both adjusted and predicted R^2 values of 0.981 (reduction of only 0.002 from Model 3), with little change in the patterns of residuals from the more complex model (Table B5).

$$\ln(BLM) = HC_{int} + \ln(DOC) + \ln(hardness) + pH + pH^2 \qquad \textbf{Model 4}$$

Table B5 Summary of MLR based on the Model 4 structure

Hydrological Classification	Model Parameter	Model Coefficient	Coefficient Significance (p-value)[a]
Ephemeral/intermittent	intercept	-24.793152	<0.0001
Intermittent	intercept	-24.731783	<0.0001
Perennial	intercept	-24.699674	<0.0001
na	DOC slope	1.028540	<0.0001
na	hardness slope	0.051764	<0.0001
na	pH slope	5.689560	<0.0001
na	pH^2 slope	-0.297282	<0.0001
Adjusted R^2		**0.982**	
Predicted R^2		**0.982**	

Note: AIC and BIC stepwise regression process resulted in the same equation as the full model.

[a] The significance of perennial and intermittent intercepts describe differences from the ephemeral/intermittent intercept, whereas the significance of the ephemeral/intermittent intercept is a difference from zero.

AIC – Akaike's Information Criterion
BIC – Bayesian Information Criterion
DOC – dissolved organic carbon
MLR – multiple linear regression
na – not applicable

As was true of the change between Models 2 and 3, the high adjusted R^2 and small differences among hydrology-specific intercepts indicated that an even simpler model than Model 4 could be adequate.

With a single intercept and single slopes for the continuous independent variables (Model 5), the adjusted and predicted R^2 values dropped to only 0.980 (from 0.981) (Table B6). Plots of calculated versus predicted BLM WQC values and MLR residuals versus independent variables (i.e., pH, DOC, and hardness) were similar to those from more complex models (Section B5).

$$\ln(BLM) = intercept + \ln(DOC) + \ln(hardness) + pH + pH^2 \qquad \textbf{Model 5}$$

Table B6 Summary of MLR based on the Model 5 structure

Model Parameter	Model Coefficient	Coefficient Significance (p-value)
Intercept	-23.0286	<0.0001
DOC slope	1.0131	<0.0001
Hardness slope	0.0466	<0.0001
pH slope	5.2063	<0.0001
pH^2 slope	-0.2627	<0.0001
Adjusted R^2	**0.980**	
Predicted R^2	**0.980**	

DOC – dissolved organic carbon
MLR – multiple linear regression

Based on the strong performance of and rationale for an MLR using the Model 5 structure, the final acute and chronic MLRs were generated using that structure (Tables B7 and B8).[14] These MLRs are proposed as the acute and chronic copper SSWQC. Table B9 provides a summary of the models described in this section.

Table B7 Final acute MLR

Model Parameter	Model Coefficient	Standard Error	Coefficient Significance (p-value)
Intercept	-22.914288	0.893512	<0.001
DOC slope	1.017377	0.008459	<0.001
Hardness slope	0.044941	0.009199	<0.001
pH slope	5.176081	0.236519	<0.001
pH^2 slope	-0.260743	0.015776	<0.001
Adjusted R^2	**0.980**		
Predicted R^2	**0.980**		

Note: Model structure based on Model 5 (Equation 1 in the main text).

DOC – dissolved organic carbon

MLR – multiple linear regression

Table B8 Final chronic MLR

Model Parameter	Model Coefficient	Standard Error	Coefficient Significance (p-value)
Intercept	-23.390522	0.893512	<0.001
DOC slope	1.017377	0.008459	<0.001
Hardness slope	0.044941	0.009199	<0.001
pH slope	5.176081	0.236519	<0.001
pH^2 slope	-0.260743	0.015776	<0.001
Adjusted R^2	**0.980**		
Predicted R^2	**0.980**		

Note: model structure based on Model 5 (Equation 2 in the main text).

DOC – dissolved organic carbon

MLR – multiple linear regression

[14] Because of the similarities between the acute and chronic BLMs (i.e., underlying toxicity datasets and chemical mechanisms), the MLR for predicting chronic BLM WQC was developed using the same methods as the acute MLR but using chronic BLM WQC instead of acute WQC as the dependent variable in the MLR.

Table B9 Summary statistics of MLR models fit to acute BLM WQC

Model Description	Development Method[a]	Adjusted R^2	Predicted R^2	AIC	BIC	Shapiro-Wilk Test p-value[b]	Scores Test p-value[c]
Model 1: Simplest model; includes pH, DOC, and hardness only (no distinction in hydrology)	full	0.969	0.968	-614	-593	<0.001	0.249
Model 2: Hydrology slopes and intercepts	full	0.973	0.971	-677	-621	<0.001	0.751
	AIC	0.973	0.971	-681	-643	<0.001	0.704
	BIC	0.973	0.971	-681	-643	<0.001	0.704
Model 3: Hydrology slopes and intercepts; pH^2 added	full	0.984	0.981	-928	-860	<0.001	0.0476
	AIC	0.984	0.981	-928	-860	<0.001	0.0476
	BIC	0.983	0.981	-918	-876	<0.001	0.00332
Model 4: Hydrology intercepts only (slopes excluded); pH^2 term always included	full	0.982	0.982	-899	-865	<0.001	0.0204
	AIC	0.982	0.982	-899	-865	<0.001	0.0204
	BIC	0.982	0.982	-899	-865	<0.001	0.0204
Model 5: No distinction in hydrology; pH^2 term always included; final models (proposed MLRs for copper SSWQC)	full (acute)	0.980	0.979	-833	-808	<0.001	0.083
	full (chronic)	0.980	0.979	-833	-808	<0.001	0.083

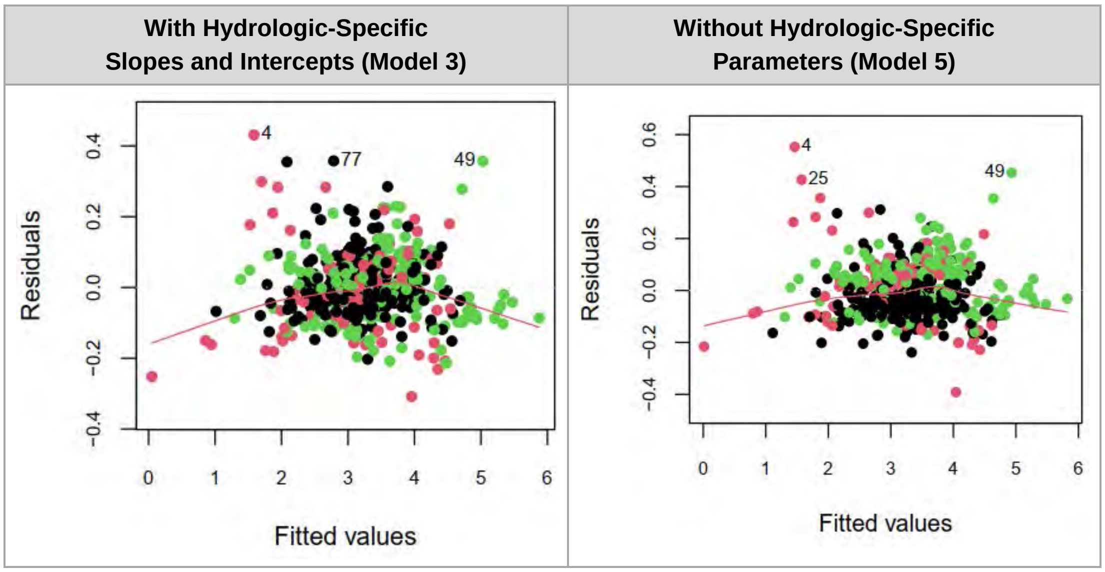
[a] Model descriptions are identified according to the key differences in model structure (left column) and the approach used to generate the model (right column). Key differences relate to the inclusion of hydrological classes as model parameters and the inclusion/exclusion of certain data. The approaches to generate the models include approaches for "full" models (i.e., all pre-determined variables included as indicated in the left column and including DOC, pH, and hardness) and AIC or BIC stepwise regression approaches, which involve sequentially adding and removing model parameters and checking improvements in model fit.

[b] Shapiro-Wilk test for normality of residuals; $p < 0.05$ indicates non-normality

[c] Score test for homogeneity of residuals; $p < 0.05$ indicates heteroscedasticity

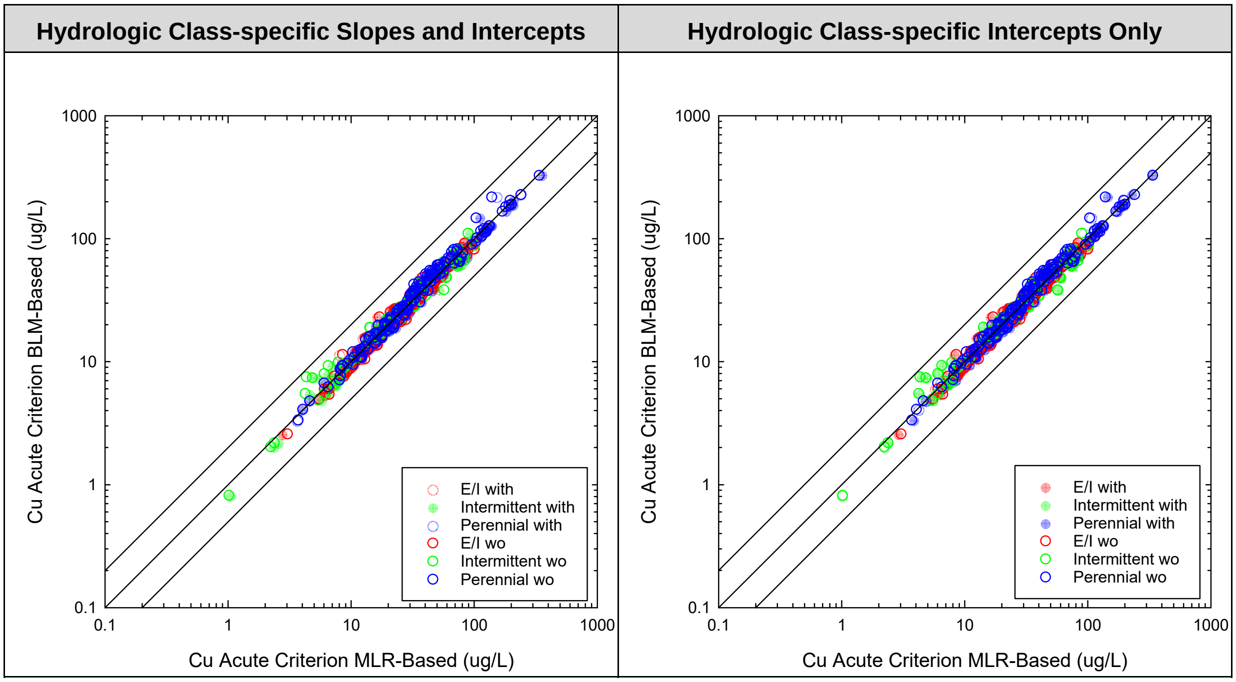
AIC - Akaike's Information Criterion
BIC – Bayesian Information Criterion
BLM – biotic ligand model
DOC – dissolved organic carbon
MLR – multiple linear regression
SSWQC – site-specific water quality criterion a
WQC – water quality criteriaon

Although the stepwise AIC and BIC models retained hydrology-specific intercepts and slopes when using Model 2 and 3 structures (Tables B3 and B4), hydrologic specificity did not eliminate residual patterns (Figure B1). Also, plots of calculated versus predicted BLM WQC values (Figure B2) show very small or negligible changes resulting from the inclusion or exclusion of hydrology-specific slopes. Moreover, the decrease in R^2 statistics (i.e., percent of variance in BLM WQC explained by the MLR) after removing hydrology-specific intercepts and/or slopes is small (< 1%) compared to the total variance explained (R^2 values, Tables B2 to B5). Together, these observations indicate that the hydrologic classification of a water body is not an important factor in site-specific MLRs relative to the continuous variables that underpin the BLM mechanisms.



Note: Point colors indicate hydrologic classification: black = ephemeral/intermittent, red = intermittent, and green = perennial. Red line is a curve fit to residuals indicating trend. Ideally, the curve would align with the dotted line.

Figure B1 Comparison of residual patterns for models with and without hydrologic classification-specific parameters



Note: Closed circles indicate the values predicted by the MLR with hydrologic-specific classification; open circles are predictions after removing hydrologic classification parameters from the MLR; dashed line is the 1:1 relationship between BLM and MLR output, and solid lines are plus or minus a factor of 2 from the 1:1 line.

Figure B2 Comparison of acute BLM-based WQC to MLR-based WQC with and without hydrologic-specific MLR terms

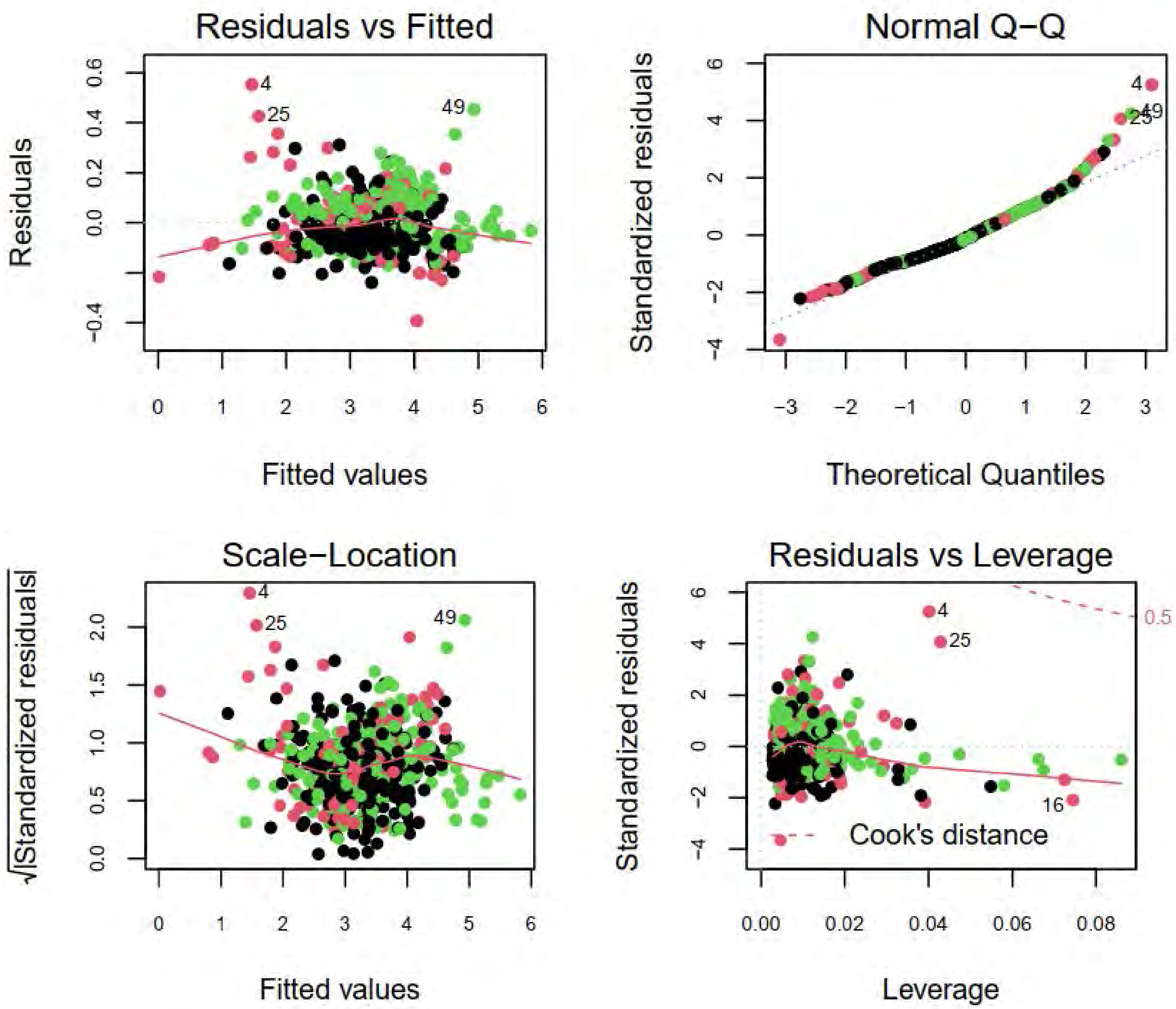
From a practical standpoint, the parsimonious Model 5 does not change the predictions of WQC exceedances when compared to the more complex models (Figure B2) and does not display any biases related to hydrology or watershed.

B5 Model Validation

Even for robust models with strong fits, like those presented in Section B4, there is inherent uncertainty associated with any MLR. This section provides a discussion of investigations into model uncertainties associated with the proposed acute and chronic copper SSWQC (Tables B7 and B8).

B5.1 Initial Model Diagnostics

Once the final MLRs were developed and proposed (Tables B7 and B8), several visual and statistical diagnostic procedures were carried out to evaluate those final models. Figure B3 provides diagnostic plots generated to evaluate the final acute MLR. The relationships shown in Figure B3 are comparable to those observed for the final chronic MLR.



Note: Figures are described in the text. Although hydrologic classifications were not included in the final MLR, the various classes are shown as colors in Figure B3: ephemeral/intermittent = black, intermittent = red, and ephemeral = green. Fitted and residual values are on a natural-log scale. The numbered points on plots correspond to potential outliers; the numbers correspond to the samples' indices within R (arbitrary ordering).

Figure B3 Model diagnostic plots for the proposed acute copper SSWQC

Figure B3 presents four diagnostic plots. The upper- and lower-left panes show MLR residuals versus the "fitted values," the natural-log of acute BLM WQC. The lines through the points indicate that there are minor trends in residuals toward the extremes of the data; however, the vast majority of data points are evenly spread around a residual of zero.

The top-right pane of Figure B3 shows a normal Q-Q plot, which is a way to visualize normality of residuals and to identify multiple populations within a distribution. A perfectly normal distribution would align with the dashed line. In general, the data align well with the dashed line, deviating from normality primarily at the upper end. This suggests that the residuals are approximately normal, but that there is some skewedness toward the extremes of the residuals (also visible as high residuals in the top-left pane). In this application, however, the deviation of residuals from normality is a minor uncertainty because the assumption of normal residuals is considered to be relatively unimportant when estimating values (e.g., BLM WQC) with linear models (Gelman and Hill 2006). The assumption of normality is important, however, when considering confidence intervals (not calculated herein) or conducting statistical tests (e.g., p-values for coefficients), neither of which were relied upon heavily to develop MLRs. Therefore, the proposed SSWQC can be used with a high degree of confidence despite minor uncertainties.

In the bottom-right pane of Figure B3, the influence of individual points is quantified using the leverage and standardized residual statistics. A Cook's distance level of 0.5 is overlaid on the figure as a dashed line, defining a general threshold for points with excessive leverage and residuals. Because no points occur beyond that threshold, no single point is considered to significantly influence the regression. This is perhaps unsurprising given how many data points are in the underlying dataset (n = 517), which makes the MLR robust despite extreme values. The points with highest leverage appear to be the perennial location samples identifiable in the top-left pane; the overall influence of the samples is low because their residual values are low.

The information provided by Figure B3 leads to the conclusion that the final acute MLR is reasonable but with some degree of model uncertainty related to groups of high residuals toward the extremes of the distribution (which are not likely "outliers" and so should be retained in the model). Considering of the strong relationship between the BLM WQC and MLR predictions (e.g., adjusted and predicted R^2 values of 0.980) and the reasonable appearance of residuals, the MLR models can be used with confidence to predict BLM WQC. This conclusion is further supported by evaluations presented in Sections 5.4.2 and 5.5 of the main text, which found MLR- and BLM-based WQC were highly comparable 1) for samples comprising the BLM dataset for the Pajarito Plateau (e.g., BLM-observed versus MLR-predicted WQC presented in Figure 5-5 of the main text); 2) across a wide range and combination of water quality conditions (e.g., Figure 5-6 of the main text); and 3) accordingly, for exceedance ratios calculated with either the BLM or MLR equation yield (e.g., Figure 5-7 of the main text).

B5.2 Sensitivity Analysis

In addition to evaluating the potential influence of hydrologic classification on the MLR, other possible factors were considered: fire-related effects caused by the Las Conchas Fire of 2011, land use effects related to urbanization, and hydrologic classification status revised using more recent hydrology protocol data.

B5.2.1 Fire effects

Additional evaluation of the potential effects of fire was conducted. This was accomplished by visualizing the BLM- and MLR-based WQC data and color-coding the data points according to whether a location was potentially impacted by the Las Conchas Fire of 2011. Figure B4 shows this for the BLM- and MLR-based WQC comparison, and Figure B5 shows the comparison of BLM- and MLR-based exceedance ratios. Functionally, the figures indicate whether there is systematic bias in the prediction of fire-affected samples compared with the prediction of samples that were not fire affected. Samples with no classification with respect to potential fire effects (n = 13) were excluded from these comparisons.

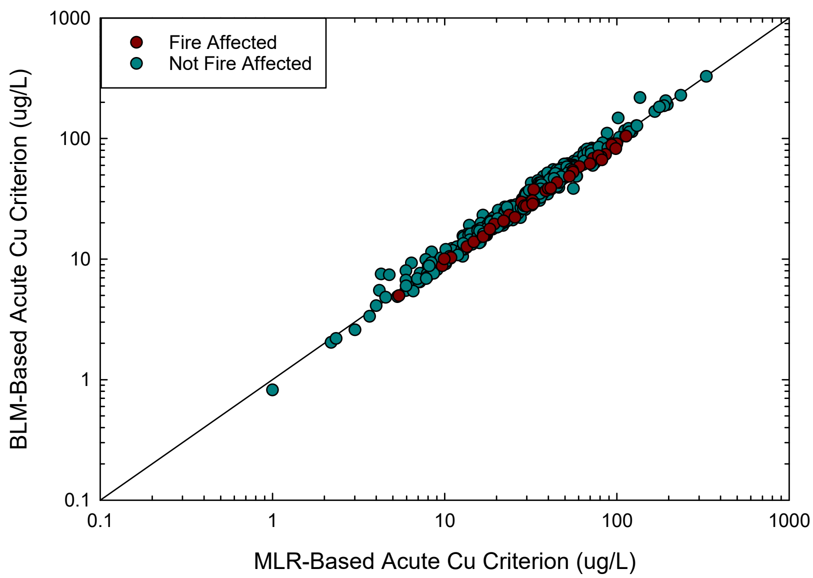


Figure B4 Comparison of BLM- and MLR-based WQC with respect to potential fire effects

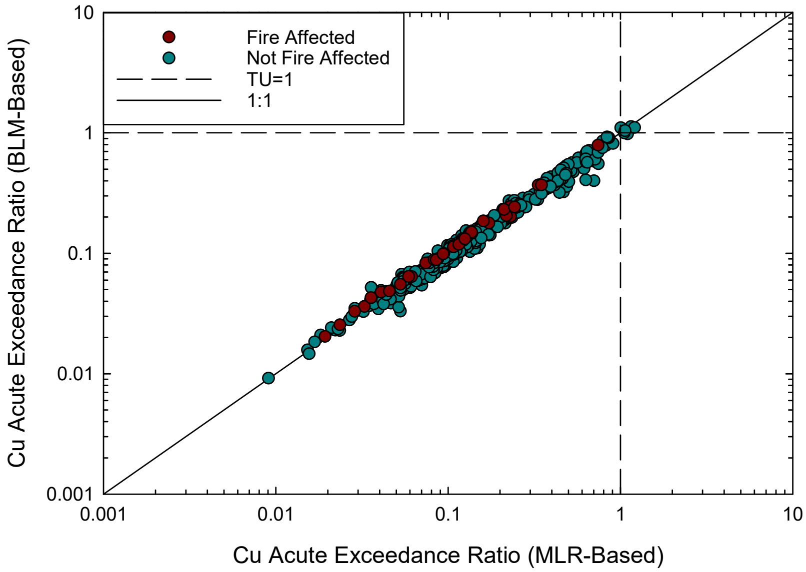


Figure B5 Comparison of BLM- and MLR-based exceedance ratios with respect to potential fire effects

Figures B4 and B5 illustrate several points:

- The relationship between the MLR- and BLM-based WQC and exceedance ratios is very strong; all points are close to the 1:1 line.
- The majority of samples were collected in watersheds (or at times) unimpacted by the Las Conchas Fire.
- WQC and exceedance ratios from fire-affected samples fall throughout the range of unaffected data, with only a few samples being relatively high; this applies to both the MLR- and BLM-based WQC and exceedance ratios.
- There does not appear to be a systematic bias in predictions, in that all points are spread evenly around the 1:1 line.

Based on these figures and evaluations of residual values described in Section B2.1, potentially fire-affected surface water samples do not have a substantial influence on MLR development, and the final MLR equation predicts potentially fire-affected samples and non-affected samples equally well.

B5.2.2 Land use effects

Similar to the evaluation of fire effects in Section B2.2, this section describes the evaluation of potential effects of land use. BLM- and MLR-based WQC data were color-coded according to whether a sample was collected from a location classified as "undeveloped" or "developed" (i.e., downstream of a LANL Resource Conservation and Recovery Act [RCRA] site). Figure B6 shows the color-coding results for the BLM-and MLR-based WQC comparison, and Figure B7 shows the comparison of BLM- and MLR-based exceedance ratios.

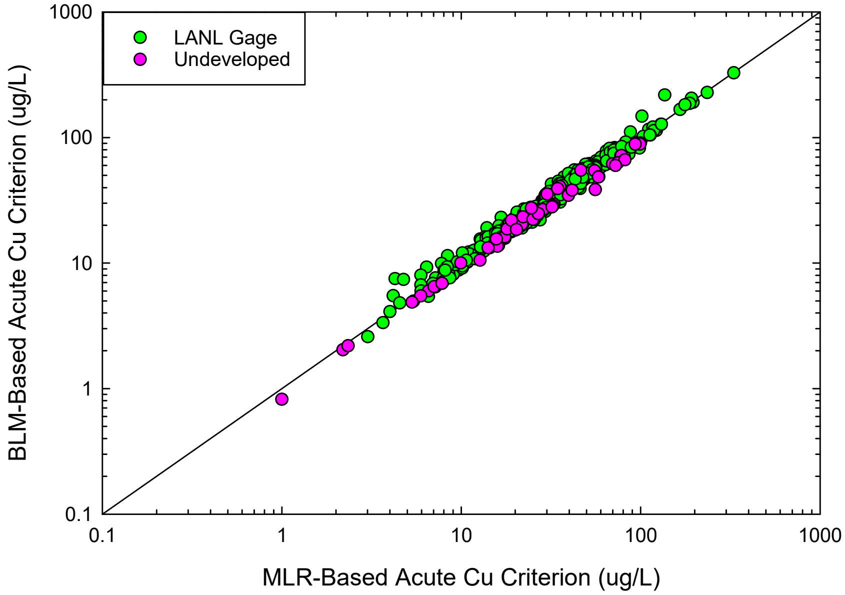


Figure B6 Comparison of BLM- and MLR-based WQC with respect to land use classifications

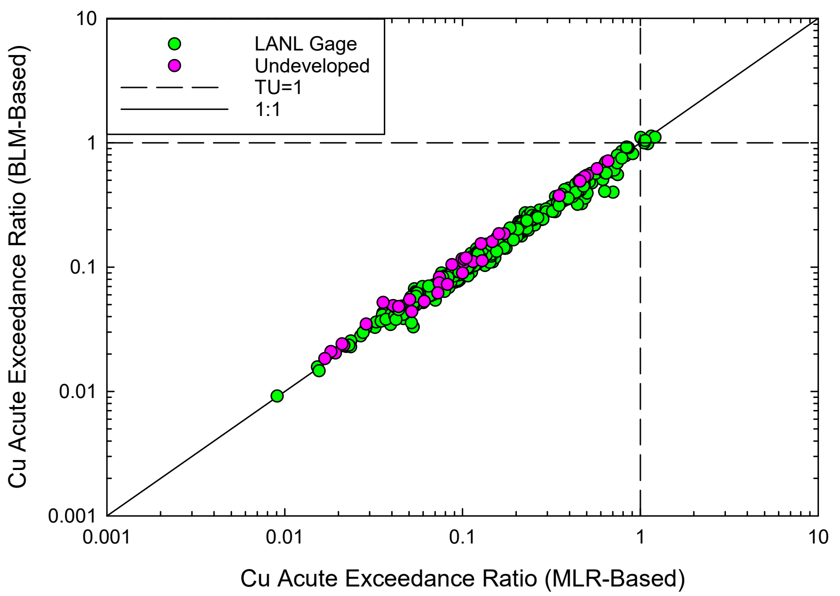


Figure B7 Comparison of BLM- and MLR-based exceedance ratios with respect to land use classification

Figures B6 and B7 illustrate several points:

- The relationship between the BLM- and MLR-based WQC and exceedance ratios is very strong; points are close to the 1:1 line.
- The majority of samples were collected downstream of LANL RCRA sites.
- BLM- and MLR-based WQC and exceedance ratios from samples collected in undeveloped locations fall throughout the ranges observed for developed locations in the BLM dataset for the Pajarito Plateau.
- There does not appear to be a systematic bias in predictions, in that all points are spread evenly around the 1:1 line.

Based on this figure and evaluations of residual values described in Section B2.1, undeveloped surface water samples do not have a substantial influence on MLR development, and the final MLR equation predicts both undeveloped and developed sample locations equally well.

B5.2.3 Alternate hydrological classifications

Section B4.2 provides a detailed evaluation of MLR models that consider current NMAC hydrologic classifications. Over the past several years, additional hydrology surveys of surface waters on the Pajarito Plateau have been conducted by NMED and the Laboratory; these surveys may lead to updated hydrology-based classifications (e.g., ephemeral, intermittent, perennial) and corresponding aquatic life use designations (e.g., limited aquatic life, marginal warm water, warm water). When developing MLRs, these potential ("alternate") classifications were considered along with current NMAC classifications; this section provides a brief overview of those findings.

As noted in Section B4.2, NMAC hydrologic classifications did not improve MLR performance, so the proposed copper SSWQC equations exclude hydrology-specific parameters (e.g., slopes and intercepts). This result was entirely consistent with the outcome of models developed using alternate hydrologic classifications based on more recent hydrological surveys and information. Table B10 shows a tabular breakdown of samples by major watershed and alternate classifications.[15] The number of samples presented in Table B10 (n = 509) is fewer than that in Table B1 (n = 517); this reflects the removal of eight samples lacking a clearly defined alternate hydrologic classification.

[15] The potential alternate hydrology classifications were developed based on findings from recent surveys conducted by NMED and the Laboratory. The alternate classifications are preliminary but included as an additional scenario to evaluate the sensitivity of MLR equations to underlying hydrology-based classifications.

Table B10 Hydrological classifications assignments for the BLM dataset by major watershed

Major Watershed	Alternate Hydrological Classification			N by Watershed
	Ephemeral	Intermittent	Perennial	
Ancho	4	0	0	**4**
Chaquehui	3	0	0	**3**
Frijoles	0	0	8	**8**
Los Alamos/Pueblo	53	117	33	**203**
Mortandad	9	25	0	**34**
Pajarito	19	35	11	**65**
Sandia	2	6	149	**157**
Water/Cañon de Valle	4	0	31	**35**
N by Alternate Hydrological Classification	**94**	**183**	**232**	**509**

BLM – biotic ligand model

N – sample size

Table B11 provides a comparison of MLRs using alternate hydrological classifications to those used in the simpler MLR equation proposed for copper SSWQC equations (i.e., Model 5, excluding hydrology-specific terms). Including hydrology-specific terms increased the adjusted and predicted R^2 values by only by 0.003 (after considering pH, DOC, and hardness). This is the same negligible change observed when comparing models with and without NMAC classification-specific parameters (Table B8). Thus, the same conclusion was reached regarding hydrology classifications: They are not necessary in the development of MLR equations to predict BLM-based WQC accurately and precisely for surface waters on the Pajarito Plateau. This conclusion is illustrated further in Figure B8.

Table B11 Summary statistics of MLR models developed using alternate hydrologic classifications

Model Description[a]		Adjusted R^2	Predicted R^2	AIC	BIC	Shapiro-Wilk Test p-value[b]	Scores Test p-value[c]
Model 3: hydrology-specific slopes and intercepts, with pH^2 terms	full	0.983	0.982	-909	-841	<0.0001	0.215
	AIC	0.983	0.982	-909	-841	<0.0001	0.215
	BIC	0.983	0.983	-906	-855	<0.0001	0.418
Model 4: hydrology-specific intercepts only	full	0.981	0.981	-848	-814	<0.0001	0.0264
	AIC	0.981	0.981	-848	-814	<0.0001	0.0264
	BIC	0.981	0.981	-848	-814	<0.0001	0.0264
Model 5: no hydrology-specific parameters	full	0.980	0.980	-823	-797	<0.0001	0.0839

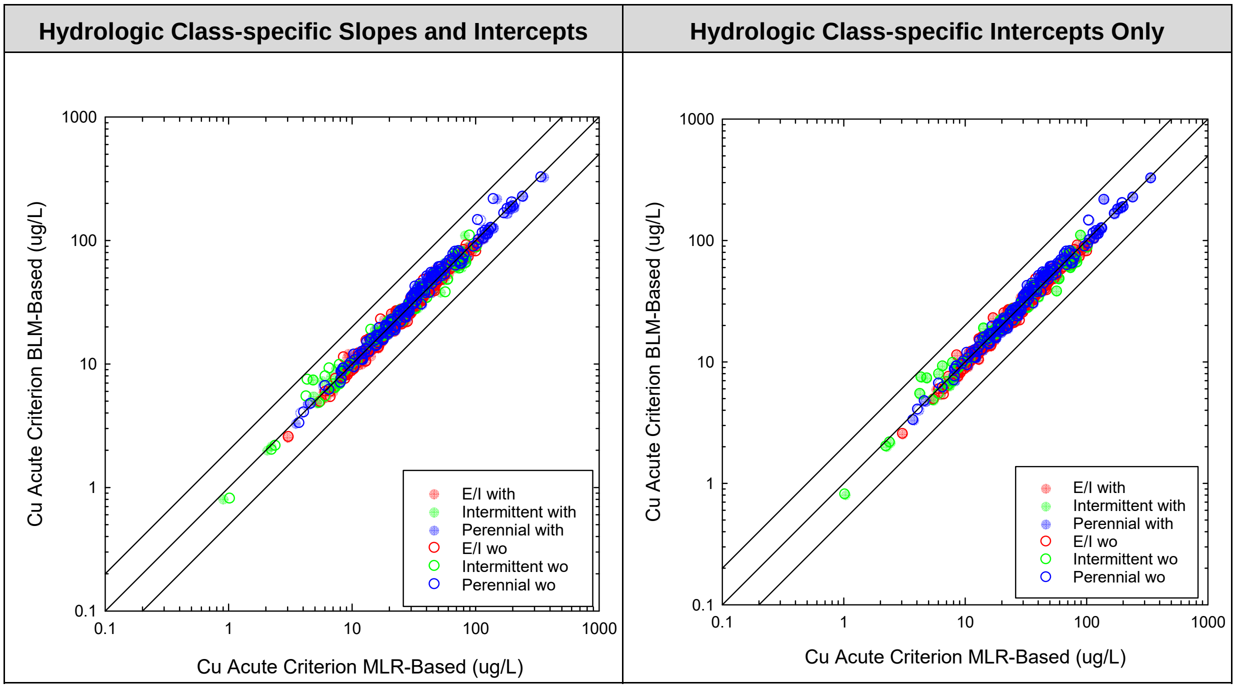
[a] Model descriptions are identified according to the key differences in model structure (left column) and the approach used to generate the model (right column). See Section B4.2 for more details.

[b] Shapiro-Wilk test for normality of residuals; $p < 0.05$ indicates non-normality.

[c] Score test for homogeneity of residuals; $p < 0.05$ indicates heteroscedasticity.

AIC – Akaike's Information Criterion BIC – Bayesian Information Criterion BLM – biotic ligand model MLR – multiple linear regression

Figure B8 shows a comparison of acute BLM- and MLR-based WQC with and without alternate hydrology terms included in the MLR equations. Consistent with the evaluation presented in Section B4.2, this figure shows very small or negligible changes resulting from the inclusion or exclusion of hydrology-specific terms.



Note: Closed circles indicate the values predicted by the MLR with hydrologic-specific classification; open circles are predictions after removing hydrologic classification parameters from the MLR; solid line is the 1:1 line.

Figure B8 Comparison of acute BLM-based WQC to MLR-based WQC with and without alternate hydrologic-specific MLR terms

B5.2.4 Predicted DOC uncertainty evaluation

As noted in Section B2.2, DOC was predicted from TOC for 124 samples that were used to develop MLRs. The development of a site-specific DOC-to-TOC ratio led to uncertainty resulting from DOC values exceeding TOC values in a subset of samples. To evaluate this uncertainty, two alternate methods for developing the MLR were investigated. The first method excluded all samples without measured DOC data, so no predictions of DOC were included in the alternate model, the results of which were then compared to results based on the final proposed model (Sections B4 and B6). The second method applied the New Mexico stream-specific default DOC-to-TOC conversion factor reported by EPA (2007) (0.815) instead of the site-specific value from Pajarito Plateau data (0.857). This change also affected the BLM output data used to develop the MLR, because DOC is one of the inputs to the BLM. Sections B5.2.4.1 and B5.2.4.2 respectively describe the outcomes of these two uncertainty evaluations.

B5.2.4.1 Alternate MLR investigation: no predicted DOC

The Model 5 structure (Section B4.2) was applied to the MLR dataset (as described in Section 5 of the main text) without the 124 samples for which DOC was predicted (Appendix A). The resulting model (based on 392 samples and the BLM acute Criterion Maximum Concentration [CMC] input) is described in Table B12.

Table B12 Alternate Model 5 MLR, no predicted DOC

Model Parameter	Model Coefficient	Standard Error	Coefficient Significance (p-value)
Intercept	-23.12523	1.05177	<0.001
DOC slope	1.05511	0.01026	<0.001
Hardness slope	-0.01473	0.01045	0.159
pH slope	5.24968	0.28402	<0.001
pH^2 slope	-0.26496	0.01925	<0.001
Adjusted R^2	**0.981**		
Predicted R^2	**0.980**		

Note: Model structure based on Model 5 (Equation 1 in the main document).

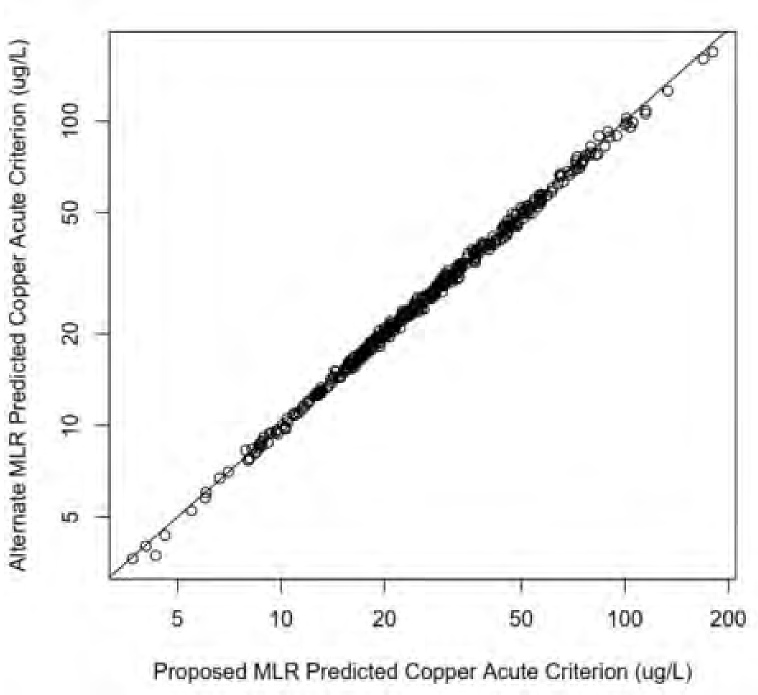
DOC – dissolved organic carbon

MLR – multiple linear regression

The alternate model is not substantially different from the proposed MLR model; for example, coefficients in the alternate model are reasonably similar to those in the model described in Table B7, and the two model fits are nearly identical. One key exception is the lack of significance of hardness in the alternate model. Significance (i.e., p-values) depends in part on sample size, so the loss of significance is not unexpected when the underlying sample size decreases by 24%.

BLM criteria were predicted using the alternate model and compared to predictions made using the proposed MLR model. Predictions are similar, tracking a 1:1 line reasonably closely (Figure B9). Although predictions tend to be lower for the alternate model (60% of 392 samples), these differences are slight. For example, the mean and median differences between predictions are 0.47 and 0.16 µg/L, respectively, and the mean and median absolute differences (as a percent)[16] are 2.4 and 2.0%. These differences are small (i.e., roughly 2%)—as shown by Figure B9—so the inclusion of predicted DOC values in the proposed MLR is not expected to have a substantive effect on MLR predictions.

[16] These differences were calculated as the average or median of the absolute value of differences between predicted acute BLM criteria divided by the prediction for the proposed MLR model (times 100%).



Note: line represents the 1:1 agreement between model predictions

Figure B9 Comparison of BLM model predictions to proposed MLR and alternate MLR model predictions using no predicted DOC samples

B5.2.4.2 Alternate MLR Investigation: EPA (2007) New Mexico DOC Prediction

The Model 5 structure (Section B4.2) was again applied to a revised dataset wherein DOC was predicted from TOC using a conversion factor of 0.815, and wherein BLM outputs (i.e., CMCs) were re-calculated using the alternate DOC inputs. The resulting model (based on 517 samples) is described in Table B13.

Table B13 Alternate Model 5 MLR, EPA (2007) New Mexico DOC prediction

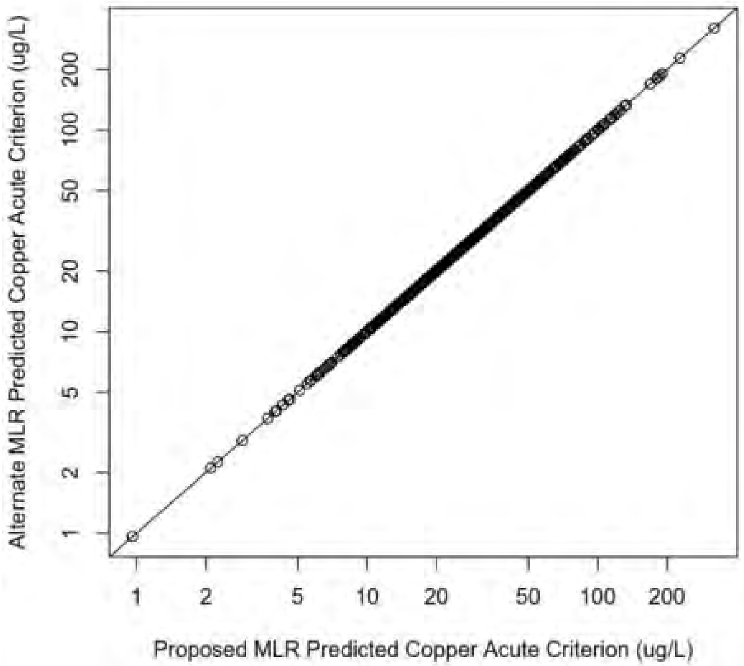
Model Parameter	Model Coefficient	Standard Error	Coefficient Significance (p-value)
Intercept	-22.880963	0.892724	<0.001
DOC slope	1.015665	0.008313	<0.001
Hardness slope	0.045126	0.009198	<0.001
pH slope	5.168510	0.236338	<0.001
pH^2 slope	-0.260276	0.015765	<0.001
Adjusted R^2	**0.980**		
Predicted R^2	**0.979**		

Note: Model structure based on Model 5 (Equation 1 in the main document).

DOC – dissolved organic carbon

MLR – multiple linear regression

This alternate model is very similar to the proposed MLR model (Table B7) in terms of coefficients, significance, and model fit. By extension, BLM criterion predictions are also very similar, as shown in Figure B10. The mean and median absolute differences between model predictions (as a percent) are 0.076% and 0.057%, respectively. There is no bias toward more or less conservative criterion predictions. In sum, the use of a lower DOC-to-TOC conversion factor would have a negligible effect on the MLR.



Note: Line represents the 1:1 agreement between model predictions.

Figure B10 Comparison of BLM model predictions to proposed MLR and alternate MLR model predictions using New Mexico DOC-to-TOC conversion factor

B6 Conclusions and Recommended copper SSWQC

Over the past 40 years, the scientific understanding of metal toxicity and bioavailability to aquatic organisms and the corresponding environmental regulations have increased. EPA has revised nationally recommended copper WQC from a simple linear equation based on hardness to a mechanistic model (the copper BLM) that incorporates several additional parameters. The BLM provides an improved method for setting copper WQC because it more accurately accounts for the modifying effect of site-specific water chemistry than do hardness-based equations (EPA 2007). Accordingly, the BLM was used to develop copper SSWQC for surface waters of the Pajarito Plateau.

Streams on the Pajarito Plateau are thoroughly monitored under a variety of EPA and NMED programs, so it is a suitable setting for developing BLM-based WQC.

The BLM dataset for the Pajarito Plateau (Appendix A) was generated from long-term monitoring data (Section 3.4 of the main text) and spans a wide range of surface water conditions. The current evaluation demonstrates that pH, DOC, and hardness concentrations account for 98% of the variation in BLM-based WQC. Potential refinements based on land use, fire effects, or hydrology were evaluated but did not result in a more accurate MLR equation.

Given these findings, the copper BLM can be simplified into a three-parameter MLR equation without losing a significant amount of accuracy and retaining the scientific rigor afforded by the BLM. The high degree of agreement between the acute and chronic MLRs and the BLM indicates that the equations presented in Section B6.1 can be adopted as copper SSWQC to provide accurate criteria that are protective of aquatic life in surface waters of the Pajarito Plateau, consistent with EPA recommendations and New Mexico WQS (20.6.4.10 NMAC).

B6.1 PROPOSED COPPER SSWQC AND APPLICABILITY

MLR equations were developed for both acute and chronic copper SSWQC for application to surface waters of the Pajarito Plateau.

The proposed acute SSWQC is as follows:

$$\boldsymbol{SSWQC_{acute}} = \boldsymbol{exp}(-\mathbf{22.914} + \mathbf{1.017} \times \boldsymbol{ln}(\boldsymbol{DOC}) + \mathbf{0.045} \times \boldsymbol{ln}(\boldsymbol{hardness}) + \mathbf{5.176} \times \boldsymbol{pH} - \mathbf{0.261} \times \boldsymbol{pH}^{\mathbf{2}})$$

The proposed chronic SSWQC is as follows:

$$\boldsymbol{SSWQC_{chronic}} = \boldsymbol{exp}(-\mathbf{23.391} + \mathbf{1.017} \times \boldsymbol{ln}(\boldsymbol{DOC}) + \mathbf{0.045} \times \boldsymbol{ln}(\boldsymbol{hardness}) + \mathbf{5.176} \times \boldsymbol{pH} - \mathbf{0.261} \times \boldsymbol{pH}^{\mathbf{2}})$$

As described in Section 3.3 of the main text, the Pajarito Plateau comprises ephemeral, intermittent, and perennial surface waters. Through the MLR development process, it was determined that hydrologic classifications did not influence the ability of the proposed acute and chronic SSWQC to accurately generate BLM-based WQC. Therefore, the acute and chronic copper SSWQC equations can be applied to any water body on the Pajarito Plateau. Most water bodies within the Laboratory's vicinity are classified as ephemeral or intermittent (20.6.4.128 NMAC); they are therefore designated as providing a limited aquatic life use and subject to acute WQC only. Other water bodies in the area are classified as perennial (20.6.4.126 and 20.6.4.121 NMAC) and are designated as providing higher-level aquatic life uses; these water bodies are subject to both acute and chronic aquatic life WQC. Unclassified surface water segments (20.6.4.98 NMAC) are designated as providing a marginal warm water aquatic life use and are subject to both acute and chronic WQC.

B7 References

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APPENDIX C. PUBLIC INVOLVEMENT PLAN

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Table C1. Schedule of Past and Planned Activities 4

Acronyms

BLM	biotic ligand model
EPA	US Environmental Protection Agency
LANL	Los Alamos National Laboratory
N3B	Newport News Nuclear BWXT-Los Alamos, LLC
NMED	New Mexico Environment Department
SSWQC	site-specific water quality criteria
SWQB	Surface Water Quality Bureau
Windward	Windward Environmental LLC
WQC	water quality criteria
WQCC	Water Quality Control Commission

C1 Introduction

On behalf of Newport News Nuclear BWXT-Los Alamos, LLC (N3B), Windward Environmental LLC (Windward) has prepared this Public Involvement Plan (hereinafter referred to as the Plan) to provide a process for public, tribal, and stakeholder engagement on the development of copper site-specific water quality criteria (SSWQC) for surface waters of the Pajarito Plateau in Los Alamos County, New Mexico. The Plan identifies the information, activities, and schedule needed to solicit participation from the various entities.

C1.1 Background

Copper SSWQC are being developed for the Pajarito Plateau in accordance with the US Environmental Protection Agency's (EPA's) nationally recommended copper water quality criteria (WQC) for the protection of aquatic life (EPA 2007). The approach utilizes EPA's copper biotic ligand model (BLM), which incorporates the effects of multiple water chemistry parameters on the bioavailability and toxicity of copper. EPA considers the copper BLM to represent the best available science for setting copper WQC (EPA 2007, 700258). The physical and chemical characteristics (i.e., BLM parameters) of Pajarito Plateau surface waters have been rigorously monitored at a variety of locations, so the Pajarito Plateau is a suitable setting for BLM-based copper SSWQC.

C1.2 Objectives

This Plan provides a general process and schedule for public, tribal, and stakeholder involvement in the development of copper SSWQC for waters of the Pajarito Plateau. Specific objectives are as follows:

- Identify potential stakeholders, tribes, and sections of the public that may be affected by the proposed copper SSWQC (Section C2).
- Establish a process to present the proposed copper SSWQC to stakeholders, tribes, and the general public, and to receive and respond to input (Section C3).
- Develop a draft schedule with milestones for stakeholder, tribal, and public engagement (Section C4).

C2 Stakeholders, Tribes, and the Public

Key stakeholders, tribes, and the public are identified in this section. These groups are the targets for involvement outreach, and it is expected that several groups from these targets will engage in the activities described in Section C3.

C2.1 Potential Stakeholders

Potential stakeholders are non-tribal public entities, agencies, and natural resource trustees that may be directly impacted by the proposed copper SSWQC. Their input will be solicited separately from public and tribal input.

Potential stakeholders include:

- New Mexico Environment Department (NMED) Surface Water Quality Bureau (SWQB)
- EPA Region 6
- US Bureau of Land Management
- US Forest Service
- National Park Service
- Los Alamos County
- Santa Fe County
- Eastern Jemez Resource Council
- Northern New Mexico's Citizen's Advisory Board
- Buckman Direct Diversion

This list is not necessarily comprehensive and may change in response to feedback from NMED SWQC and EPA Region 6.

C2.2 Tribes

Tribal outreach is intended to involve leadership/representatives of local pueblos; these engagements will be separate from stakeholder and public engagements. All tribal members will be welcome to attend public engagements as well. Local pueblos identified for outreach include:

- San Ildefonso Pueblo
- Santa Clara Pueblo
- Cochiti Pueblo
- Jemez Pueblo

This list is not necessarily comprehensive and may change in response to feedback from NMED SWQB and EPA Region 6.

C2.3 General Public

The public includes any individuals on or around the Pajarito Plateau, including but not limited to those living in and near Los Alamos County, Cochiti Lake, San Ildefonso Pueblo, Santa Clara Pueblo, Cochiti Pueblo, and Jemez Pueblo. Public engagements will be open to all who wish to attend, and members of the public will have the right to provide comments on the draft SSWQC demonstration report.

C3 Planned Activities

There are 16 activities associated with the public involvement process: 13 to be conducted by Windward and N3B, and 3 to be conducted by stakeholders, tribes, and the public. Activities to be conducted by Windward or N3B include:

1. Submit draft work plan for developing copper SSWQC for review by NMED SWQB and EPA Region 6.[1]
2. Prepare response to NMED and EPA comments on the work plan.[2]
3. Prepare and submit drafts of the copper SSWQC demonstration report for initial and final review by NMED and EPA.[3]
4. Submit revised draft Demonstration Report, comment responses, and supporting data to NMES SWQB and EPA.
5. Prepare response to NMED SWQB and EPA comments on the Demonstration Report and revise the report accordingly.
6. Submit draft copper SSWQC demonstration report to appropriate physical locations for public review and host the digital version of the report on the N3B and Individual Permit (IP) Public websites; an abbreviated fact sheet describing the proposed SSWQC will also be hosted on the IP Public website (https://ext.em-la.doe.gov/ips) and on the N3B outreach website (https://n3b-la.com/outreach).
7. Notify the public of the open comment period (45 days) in local newspapers (the Santa Fe New Mexican, the Rio Grande Sun in Española, and the Los Alamos Daily Post), on the IP public website (https://ext.em-la.doe.gov/ips), on the N3B Cleanup Outreach website (https://n3b-la.com/outreach), and through direct communication with identified stakeholders (Section C2).

[1] This was complete as of September 9, 2020. NMED SWQB and EPA Region 6 provided comments to N3B on March 9, 2021.

[2] This was complete as of July 28, 2021.

[3] This was complete as of July 28, 2021. NMED SWQB and EPA Region 6 provided comments to N3B on November 9, 2021.

8. Hold a series of meetings in person and/or by webinar for stakeholders, tribes, and the public.
9. Review comments submitted via email to publiccomment@em-la.doe.gov.
10. Prepare formal response to public comments and append to the final copper SSWQC demonstration report.
11. Finalize and submit demonstration report to the New Mexico Water Quality Control Commission (WQCC) as part of a formal petition to change New Mexico's Water Quality Standards.

Stakeholders, tribes, and the public are to review documents, attend appropriate engagements, and submit comments via email to N3BOutreach@em-la.doe.gov.

C4 Schedule of Activities

Table C1 provides a tentative schedule of the activities listed in Section C3. The schedule shows the order of past and intended activities and their relative position over time. Specific dates are subject to change.

Table C1 Schedule of Past and Planned Activities

Activity	Acting Group(s)	Target Audience	Dates
Submit draft Work Plan	N3B/LANL	NMED SWQB and EPA Region 6	September 9, 2020
Receive NMED/EPA Region 6 comments on Work Plan	NMED SWQB and EPA Region 6	N3B/LANL	March 9, 2021
Respond to NMED/EPA comments on Work Plan	N3B/LANL	NMED SWQB and EPA Region 6	July 28, 2021
Submit draft Demonstration Report to NMED/EPA	N3B/LANL	NMED SWQB and EPA Region 6	July 28, 2021 (corrected August 20, 2022)
Submit revised draft Demonstration Report, comment responses, and supporting data to NMED/EPA	N3B/LANL	NMED SWQB and EPA Region 6	March 30, 2022 (report), April 18, 2022 (comment responses), and May 31, 2022 (additional materials upon NMED request)
Receive NMED/EPA comments on Demonstration Report	NMED SWQB and EPA Region 6	N3B/LANL	March 31, 2023
Prepare response to NMED and EPA comments on the Demonstration Report	N3B/LANL	NMED SWQB and EPA Region 6	May to August 2023
Submit draft Demonstration Report	N3B/LANL	NMED SWQB and EPA Region 6	August 2023
Notify stakeholders, tribes, and public about copper SSWQC and comment period	N3B/LANL	stakeholders, tribes, and public	Estimated September to November 2023
Meet with stakeholders	N3B/LANL	stakeholders	Estimated September to November 2023

Activity	Acting Group(s)	Target Audience	Dates
Meet with tribes	N3B/LANL	tribes	Estimated September to November 2023
Hold public meeting	N3B/LANL	public	Estimated October 2023
Develop response to public comments	N3B/LANL	stakeholders, tribes, public, WQCC	Estimated October to December 2023
Finalize Demonstration Report	N3B/LANL	stakeholders, tribes, public, WQCC	Estimated January, 2024
File formal petition with final Demonstration Report and response to comments	N3B/LANL	WQCC	Estimated January, 2024

EPA – Environmental Protection Agency
LANL – Los Alamos National Laboratory
N3B – Newport News Nuclear BWXT Los Alamos
NMED – New Mexico Environment Department
SWQB –Surface Water Quality Bureau
SSWQC – site-specific water quality criteria
WQCC – Water Quality Control Commission

C5 Reference

EPA (U.S. Environmental Protection Agency), February 2007. "Aquatic Life Ambient Freshwater Quality Criteria - Copper," 2007 Revision, EPA-822-R-07-001, Office of Water, Office of Science and Technology, Washington, D.C. (EPA 2007, 700258)

APPENDIX D. THREATENED AND ENDANGERED SPECIES CONSIDERATIONS

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Tables

Table D-1	Rio Grande copper concentrations and WQC	3

Acronyms

AWQC	ambient water quality criteria
BLM	biotic ligand model
DOC	dissolved organic carbon
EPA	US Environmental Protection Agency
ESA	Endangered Species Act
ID	identification
MLR	multiple linear regression
NMFS	National Marine Fisheries Service
SSWQC	site-specific water quality criteria
T&E	threatened and endangered
TU	toxic unit
USFWS	US Fish and Wildlife Service
WQC	water quality criteria

D1 Overview

This appendix identifies threatened and endangered (T&E) species that may occur on or in the vicinity of the Pajarito Plateau. It also discusses the protectiveness of the proposed copper site-specific water quality criteria (SSWQC) to these species.

In accordance with Section 7 of the federal Endangered Species Act (ESA), the Environmental Protection Agency (EPA) consults with the US Fish and Wildlife Service (USFWS) to ensure that any action[1] authorized by the EPA is not likely to jeopardize the continued existence of T&E species or result in the destruction or adverse modification of T&E species or their critical habitats. In the context of this SSWQC proposal, such action would include adoption of EPA's national recommended ambient water quality criteria (AWQC) for copper (EPA 2007) as this is the basis of the proposed copper SSWQC. Importantly, the proposed SSWQC is not associated with any new actions or discharges that would result in increased copper loading to surface waters of the Pajarito Plateau.

EPA's national recommended AWQC for the protection of aquatic life are derived from empirical toxicity data and are designed to be stringent enough to protect sensitive aquatic species potentially exposed to a contaminant in any water body in the United States. Below these thresholds, significant adverse effects on aquatic communities are not anticipated. In accordance with EPA guidelines (EPA 1985), AWQC are only developed if an eight-family rule is met, which requires toxicity results with at least one species in at least eight different families. The acute toxicity dataset used to derive EPA's national recommended AWQC for copper comprises empirical toxicity data for 39 species across 27 genera and 20 families.[2] As such, the database used to develop the copper AWQC represents a diverse group of aquatic species and, as discussed in this appendix, is expected to provide sufficient protection to both aquatic and terrestrial T&E species.

Sections D2 and D3 identify aquatic T&E species that may reside in surface waters downstream of the Pajarito Plateau and discuss how the SSWQC is protective of these species.

Sections D4 through D8 identify terrestrial T&E species that may reside in the vicinity of the Pajarito Plateau and discuss how the SSWQC is protective of these species.

[1] Under the ESA, an "action" includes all activities or programs of any kind authorized, funded, or carried out, in whole or in part, by Federal agencies in the United States. This includes promulgation of regulations, including oversight of State and tribal water quality criteria.

[2] As discussed in the main text, chronic AWQC are based on an acute-to-chronic ratio rather than a distinct chronic toxicity dataset; therefore, the chronic dataset also is composed of 39 species, 27 genera, and 20 families.

D2 Rio Grande Cutthroat Trout (*Oncorhynchus clarkii virginalis*)

The Rio Grande cutthroat trout is a subspecies of cutthroat trout (genus *Oncorhynchus*), the range of which spans the Rio Grande, the Pecos River, and the Canadian River drainages of southern Colorado and northern New Mexico (Pritchard and Cowley 2006). Populations are spatially restricted and fragmented, primarily confined to headwater streams and small high-elevation lakes. Cutthroat trout are opportunistic foragers that feed on aquatic and terrestrial invertebrates such as midge (Chironomidae) larvae, mayflies (Ephemeroptera), ostracods, caddisflies (Tricoptera), and other flies (Diptera) (RGCT Conservation Team 2013; Pritchard and Cowley 2006).

The SSWQC is intended to be protective of aquatic life species, including Rio Grande cutthroat trout and their prey. For example, the copper biotic ligand model (BLM) database includes acute and/or chronic toxicity test results for cutthroat trout (*O. clarkii*), Lahontan cutthroat trout (*O. clarkii henshawi*), and several other taxonomically similar salmonids (e.g., *Oncorhynchus* spp. and *Salmo* spp.).

Of the species included in the copper BLM database, salmonids are not the most sensitive. Therefore, the BLM (and, by extension, the SSWQC) is protective of salmonids as well as sensitive invertebrates, including potential prey items. In addition, the USFWS and the National Marine Fisheries Service (NMFS) previously concluded the copper BLM provides an improved level of protection to these salmonids relative to hardness-based water quality criteria (WQC) (NMFS 2014; USFWS 2015). Therefore, implementing the SSWQC is not expected to adversely affect Rio Grande cutthroat trout.

Copper concentrations in the Rio Grande were compared to copper WQC (Table D-1). In 110 samples collected at 5 separate sampling locations along the main stem of the Rio Grande near the Pajarito Plateau (i.e., Taos Junction Bridge, Otowi Bridge, Cochiti Dam, San Felipe, and Alameda Bridge) between 2005 and 2021, there were no exceedances of acute or chronic copper BLM-based criteria, proposed copper SSWQC, or New Mexico's current hardness-based criteria. These results show that moving from the hardness-based WQC to the proposed SSWQC would not adversely affect aquatic species in the Rio Grande downstream of the Pajarito Plateau.

Table D-1 Rio Grande copper concentrations and WQC

																BLM (µg/L)		MLR SSWQC (µg/L)		New Mexico Hardness-based Criteria (µg/L)		BLM		MLR SSWQC		New Mexico Hardness-based Criteria	
Location ID	Date	X	Y	Temp. (C)	Copper (µg/L)	pH	DOC (mg/L)	Hardness (mg/L CaCO^{3})	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Sulfate (mg/L)	Cl (mg/L)	Alkalinity (mg/L CaCO^{3})	Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute TU	Chronic TU	Acute TU	Chronic TU	Acute TU	Chronic TU
Rio Grande below Taos Junction Bridge near Taos, NM	12/5/05	1054516	361912.12	1.5	1	8.5	1.02	87.7	26.8	5.06	14.5	2.63	24	4.57	171	9	6	12	7.1	12	8.3	0.11	0.18	0.08	0.14	0.08	0.12
Rio Grande below Taos Junction Bridge near Taos, NM	4/18/06	1054516	361912.12	13	1.9	8.8	1	93.1	27.4	6	19.1	2.91	33.2	5.89	194	14	8	14	8.5	13	8.8	0.14	0.23	0.14	0.22	0.15	0.22
Rio Grande below Taos Junction Bridge near Taos, NM	8/7/06	1054516	361912.12	22	0.92	8.6	1.92	85.8	25.2	5.57	20.2	3.29	28.8	5.71	195	27	17	24	15	12	8.2	0.03	0.05	0.04	0.06	0.08	0.11
Rio Grande below Taos Junction Bridge near Taos, NM	11/27/06	1054516	361912.12	4	0.78	8.5	1.4	72.3	21.9	4.3	13	2.51	19.4	3.76	151	12	8	16	9.7	10	7.1	0.06	0.10	0.05	0.08	0.08	0.11
Rio Grande below Taos Junction Bridge near Taos, NM	4/30/07	1054516	361912.12	15	3.4	8.5	8.6	119	35.2	7.49	27.4	3.79	74.4	7.84	207	100	62	103	63	16	11	0.03	0.05	0.03	0.05	0.21	0.31
Rio Grande below Taos Junction Bridge near Taos, NM	8/13/07	1054516	361912.12	21	2.6	8.2	4.15	59.7	17.6	3.84	11.3	2.45	19	3.12	139	37	23	37	23	8.6	6	0.07	0.11	0.07	0.11	0.30	0.43
Rio Grande below Taos Junction Bridge near Taos, NM	11/5/08	1054516	361912.12	9	2.6	8.4	1.22	100	29.1	6.66	19	2.95	33.1	6.38	218	12	7	13	7.9	14	9.3	0.22	0.36	0.20	0.33	0.19	0.28
Rio Grande below Taos Junction Bridge near Taos, NM	6/4/09	1054516	361912.12	15	1.2	8.1	5.99	142	42.9	8.7	29.9	4.65	94.2	7.37	205	50	31	51	31	20	13	0.02	0.04	0.02	0.04	0.06	0.09
Rio Grande below Taos Junction Bridge near Taos, NM	8/11/09	1054516	361912.12	19.5	0.8	8.7	2.05	104	30.8	6.68	21.9	2.95	41.5	6.67	210	31	19	27	17	15	9.7	0.03	0.04	0.03	0.05	0.05	0.08
Rio Grande below Taos Junction Bridge near Taos, NM	11/16/09	1054516	361912.12	7.2	1	8.6	1.38	103	30.1	6.66	17.9	2.93	35.1	5.81	211	14	9	17	10	14	9.5	0.07	0.11	0.06	0.10	0.07	0.11
Rio Grande below Taos Junction Bridge near Taos, NM	5/4/10	1054516	361912.12	12	1.3	8.3	4.49	91.4	28	5.25	14.3	2.81	36.3	4.29	158	39	24	45	27	13	8.6	0.03	0.05	0.03	0.05	0.10	0.15
Rio Grande below Taos Junction Bridge near Taos, NM	8/9/10	1054516	361912.12	20.8	1.1	8.7	1.63	108	31.9	7.02	20.2	3.06	39.6	6.45	210	25	16	22	13	15	10	0.04	0.07	0.05	0.08	0.07	0.11
Rio Grande at Otowi Bridge, NM	12/13/05	1060832.8	355228.2	2	1.5	8.4	1.58	123	38.7	6.39	18.4	2.72	33.6	6.1	224	14	9	17	10	17	11	0.11	0.18	0.09	0.15	0.09	0.14

Location ID	Date	X	Y	Temp. (C)	Copper (µg/L)	pH	DOC (mg/L)	Hardness (mg/L CaCO³)	Ca	Mg	Na	K	Sulfate	Cl	Alkalinity (mg/L CaCO³)	BLM (µg/L)		MLR SSWQC (µg/L)		New Mexico Hardness-based Criteria (µg/L)		BLM		MLR SSWQC		New Mexico Hardness-based Criteria	
									(mg/L)							Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute TU	Chronic TU	Acute TU	Chronic TU	Acute TU	Chronic TU
Rio Grande at Otowi Bridge, NM	4/19/06	1060832.8	355228.2	12	1.6	8.4	1.75	109	34	5.81	16.1	2.39	36.7	5.11	195	17	11	19	12	15	10	0.09	0.15	0.08	0.13	0.11	0.16
Rio Grande at Otowi Bridge, NM	8/8/06	1060832.8	355228.2	24.5	1.3	8.2	2.07	115	36.9	5.49	19	3.75	34.9	6.45	244	22	14	19	12	16	10	0.06	0.10	0.07	0.11	0.08	0.13
Rio Grande at Otowi Bridge, NM	11/28/06	1060832.8	355228.2	5.5	0.78	8.4	0.73	93.2	28.7	5.25	14.8	2.38	31.5	4.61	186	7	4	7.6	4.7	13	8.8	0.12	0.19	0.10	0.17	0.06	0.09
Rio Grande at Otowi Bridge, NM	5/1/07	1060832.8	355228.2	16	1.8	8.4	6.7	107	32.9	6	19.4	2.76	51.4	6.31	198	70	44	73	45	15	9.9	0.03	0.04	0.02	0.04	0.12	0.18
Rio Grande at Otowi Bridge, NM	8/14/07	1060832.8	355228.2	23	1.5	8.2	3.74	94.7	29.5	5.13	14.2	2.18	33.4	3.79	188	36	23	34	21	13	8.9	0.04	0.07	0.04	0.07	0.12	0.17
Rio Grande at Otowi Bridge, NM	11/20/07	1060832.8	355228.2	7.5	0.8	8.5	1.07	99.1	30.2	5.78	18.3	2.79	29.8	5.85	213	11	7	12	7.5	14	9.3	0.08	0.12	0.07	0.11	0.06	0.09
Rio Grande at Otowi Bridge, NM	11/7/08	1060832.8	355228.2	4	0.64	8.3	2.32	130	39.7	7.56	21.9	2.84	39.9	8.01	273	20	12	23	14	18	12	0.03	0.05	0.03	0.05	0.04	0.05
Rio Grande at Otowi Bridge, NM	5/6/09	1060832.8	355228.2	11	1.8	8.1	6.78	82.9	26.2	4.25	9.91	1.98	30.5	2.7	141	48	30	57	35	12	7.9	0.04	0.06	0.03	0.05	0.15	0.23
Rio Grande at Otowi Bridge, NM	8/13/09	1060832.8	355228.2	19.5	0.86	8.1	4.18	115	37.2	5.44	13.2	2.11	47.1	3.19	191	35	22	35	22	16	11	0.02	0.04	0.02	0.04	0.05	0.08
Rio Grande at Otowi Bridge, NM	11/17/09	1060832.8	355228.2	6.5	0.56	8.5	2.06	127	39.5	6.88	20.5	2.68	39.5	6.88	244	20	13	24	15	18	11	0.03	0.04	0.02	0.04	0.03	0.05
Rio Grande at Otowi Bridge, NM	5/6/10	1060832.8	355228.2	11	1	8.2	4.28	99.3	31.3	5.15	12.3	2.06	37.6	3.45	164	34	21	39	24	14	9.3	0.03	0.05	0.03	0.04	0.07	0.11
Rio Grande at Otowi Bridge, NM	8/11/10	1060832.8	355228.2	20.3	0.9	8.2	3.28	118	37.4	5.98	12.7	2.07	39	3.97	204	31	19	30	19	16	11	0.03	0.05	0.03	0.05	0.06	0.08
Rio Grande below Cochiti Dam, NM	11/19/09	1061926.2	353704.8	9.7	0.5	8.2	2.44	122	38.5	6.29	18	2.65	39.3	5.92	236	20	12	22	14	17	11	0.03	0.04	0.02	0.04	0.03	0.05
Rio Grande below Cochiti Dam, NM	5/10/10	1061926.2	353704.8	12.7	1.2	8.2	4.52	92.4	29.4	4.62	11.8	2.1	33.8	3.49	162	36	22	41	25	13	8.7	0.03	0.05	0.03	0.05	0.09	0.14
Rio Grande below Cochiti Dam, NM	8/16/10	1061926.2	353704.8	22.7	0.79	7.8	3.56	121	39	5.64	14.4	2.62	37.9	4.33	213	23	14	22	14	17	11	0.04	0.06	0.04	0.06	0.05	0.07
Rio Grande below Cochiti Dam, NM	12/2/10	1061926.2	353704.8	6.2	0.56	8.2	2.05	122	38.2	6.44	18.4	2.66	38	5.74	242	16	10	19	11	17	11	0.03	0.06	0.03	0.05	0.03	0.05
Rio Grande below Cochiti Dam, NM	6/2/11	1061926.2	353704.8	16.4	0.73	8.2	3.52	119	37	6.49	16	2.48	44.3	4.64	204	31	19	32	20	16	11	0.02	0.04	0.02	0.04	0.05	0.07
Rio Grande below Cochiti Dam, NM	8/12/11	1061926.2	353704.8	23.1	0.56	7.9	3.8	99.9	31	5.49	13.1	2.97	34.2	3.44	181	26	16	26	16	14	9.3	0.02	0.03	0.02	0.04	0.04	0.06
Rio Grande below Cochiti Dam, NM	12/7/11	1061926.2	353704.8	5.6	0.8	8	2.2	105	32.5	5.71	15.3	2.51	31.6	5.14	204	14	9	16	10	15	9.7	0.06	0.09	0.05	0.08	0.05	0.08
Rio Grande below Cochiti Dam, NM	4/25/12	1061926.2	353704.8	13.1	1.5	8	3.39	90.2	27.9	5.01	12.3	2.1	29.1	4.25	178	23	14	25	16	13	8.5	0.07	0.11	0.06	0.09	0.12	0.18
Rio Grande below Cochiti Dam, NM	8/22/12	1061926.2	353704.8	22.4	0.9	8.2	4.07	120	38.1	5.93	14.8	3.06	41.4	3.55	200	40	25	37	23	17	11	0.02	0.04	0.02	0.04	0.05	0.08
Rio Grande below Cochiti Dam, NM	12/18/12	1061926.2	353704.8	4.7	0.8	8.2	2.56	130	40.9	6.98	18.1	2.78	46.5	5.21	226	20	12	23	14	18	12	0.04	0.06	0.03	0.06	0.04	0.07
Rio Grande below Cochiti Dam, NM	5/9/13	1061926.2	353704.8	13.6	0.8	7.9	2.47	125	38.5	7	19.1	2.59	52.1	5.07	224	16	10	17	10	17	11	0.05	0.08	0.05	0.08	0.05	0.07
Rio Grande below Cochiti Dam, NM	8/1/13	1061926.2	353704.8	22.4	0.8	8	4.62	125	39.6	6.44	20.4	4.07	52	4.72	238	38	23	35	22	17	11	0.02	0.03	0.02	0.04	0.05	0.07
Rio Grande below Cochiti Dam, NM	12/17/13	1061926.2	353704.8	3.8	0.8	8.1	2.67	121	37.7	6.44	18.1	2.82	38.9	5.78	225	19	12	22	14	17	11	0.04	0.07	0.04	0.06	0.05	0.07
Rio Grande below Cochiti Dam, NM	5/12/14	1061926.2	353704.8	13.4	0.8	8.1	3.08	125	39.2	6.54	19.2	2.73	56.5	5.5	213	24	15	26	16	17	11	0.03	0.05	0.03	0.05	0.05	0.07

Location ID	Date	X	Y	Temp. (C)	Copper (µg/L)	pH	DOC (mg/L)	Hardness (mg/L CaCO^3)	Ca	Mg	Na	K	Sulfate	Cl	Alkalinity (mg/L CaCO^3)	BLM (µg/L)		MLR SSWQC (µg/L)		New Mexico Hardness-based Criteria (µg/L)		BLM		MLR SSWQC		New Mexico Hardness-based Criteria	
									(mg/L)							Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute TU	Chronic TU	Acute TU	Chronic TU	Acute TU	Chronic TU
Rio Grande below Cochiti Dam, NM	8/21/14	1061926.2	353704.8	22.3	1.4	7.9	3.37	121	38.8	5.81	16.2	3.57	41	4.18	215	24	15	23	14	17	11	0.06	0.09	0.06	0.10	0.08	0.13
Rio Grande below Cochiti Dam, NM	1/5/15	1061926.2	353704.8	2.6	0.8	8.1	2.05	108	33.6	5.93	18.7	2.65	37.2	5.53	217	14	9	17	10	15	10	0.06	0.09	0.05	0.08	0.05	0.08
Rio Grande below Cochiti Dam, NM	3/28/15	1061926.2	353704.8	10.2	1.6	7.7	3.02	95.5	29.6	5.27	16.6	2.65	29.8	6.17	197	15	9	16	10	13	9	0.11	0.17	0.10	0.16	0.12	0.18
Rio Grande below Cochiti Dam, NM	8/11/15	1061926.2	353704.8	22.6	0.8	7.9	3.32	111	35	5.66	14.2	2.71	34.8	3.83	192	23	15	23	14	15	10	0.03	0.06	0.03	0.06	0.05	0.08
Rio Grande below Cochiti Dam, NM	1/25/16	1061926.2	353704.8	2.9	0.8	7.9	2.25	112	34.6	6.27	16.4	2.42	38.1	5.62	105	14	8	15	9	15	10	0.06	0.10	0.05	0.09	0.05	0.08
Rio Grande below Cochiti Dam, NM	5/25/16	1061926.2	353704.8	15.7	1.1	8.1	4.29	99	30.8	5.32	12.7	2.48	32.6	3.82	84	33	21	36	22	13	9	0.03	0.05	0.03	0.05	0.08	0.12
Rio Grande below Cochiti Dam, NM	8/25/16	1061926.2	353704.8	21.5	0.96	8	3.54	117	37.6	5.4	14.1	2.73	44	3.92	97.4	27	17	27	17	16	10	0.03	0.06	0.04	0.06	0.06	0.09
Rio Grande below Cochiti Dam, NM	12/12/16	1061926.2	353704.8	5.6	0.66	8.1	2.2	123	37.7	6.8	19	2.59	43.2	5.82	112	16	10	18	11	16	11	0.04	0.07	0.04	0.06	0.04	0.06
Rio Grande below Cochiti Dam, NM	4/26/17	1061926.2	353704.8	12.7	1.2	7.9	5.66	86.2	26.9	4.57	10.4	1.98	31.7	3.19	70.8	34	21	39	24	12	8	0.04	0.06	0.03	0.05	0.10	0.15
Rio Grande below Cochiti Dam, NM	8/17/17	1061926.2	353704.8	--	1.4	8	3.6	75.2	23.6	3.87	9.81	1.76	31.4	4.3	98.4	23	14	27	16	10	7	0.06	0.10	0.05	0.08	0.14	0.20
Rio Grande below Cochiti Dam, NM	1/24/18	1061926.2	353704.8	3.1	0.66	7.8	2.1	114	35.5	6	17.6	2.59	36.1	5.79	104	12	7	13	8	15	10	0.06	0.09	0.05	0.08	0.04	0.07
Rio Grande below Cochiti Dam, NM	4/12/18	1061926.2	353704.8	10.7	0.55	8	1.97	116	35.6	6.37	18.6	2.81	36.2	6.24	107	14	9	15	9	15	10	0.04	0.06	0.04	0.06	0.04	0.05
Rio Grande below Cochiti Dam, NM	8/20/18	1061926.2	353704.8	22.4	0.99	7.9	3.11	130	41.1	6.57	14.8	2.66	55.7	3.73	101	22	14	21	13	17	11	0.04	0.07	0.05	0.08	0.06	0.09
Rio Grande below Cochiti Dam, NM	2/26/19	1061926.2	353704.8	4	1.1	7.7	1.8	129	39.4	7.22	20.2	2.7	50.4	7.22	112	9	6	10	6	17	11	0.12	0.19	0.11	0.18	0.06	0.10
Rio Grande below Cochiti Dam, NM	5/21/19	1061926.2	353704.8	11.5	3.7	8.2	5.4	75.5	23.8	3.84	7.96	1.94	20.9	2.77	65.4	41	26	49	30	10	7	0.09	0.14	0.08	0.12	0.36	0.53
Rio Grande below Cochiti Dam, NM	8/19/19	1061926.2	353704.8	22.3	1.1	7.9	2.98	76	24.2	3.71	9.05	2.13	18.9	2.69	73.5	20	12	20	12	10	7	0.06	0.09	0.06	0.09	0.11	0.16
Rio Grande below Cochiti Dam, NM	1/13/20	1061926.2	353704.8	2.6	0.68	7.9	2.11	107	33.2	5.86	16	2.37	37.5	6	102	13	8	14	9	14	9	0.05	0.09	0.05	0.08	0.05	0.07
Rio Grande below Cochiti Dam, NM	5/11/20	1061926.2	353704.8	15.1	0.85	8	2.73	107	33.2	5.87	15.6	2.39	37.8	5.98	100	19	12	21	13	14	9	0.04	0.07	0.04	0.07	0.06	0.09
Rio Grande below Cochiti Dam, NM	8/17/20	1061926.2	353704.8	23	0.9	8.1	3.02	130	40.7	6.92	16.5	2.57	60.7	4.44	100	28	17	25	16	17	11	0.03	0.05	0.04	0.06	0.05	0.08
Rio Grande below Cochiti Dam, NM	1/7/21	1061926.2	353704.8	3.1	0.72	8.3	2.02	124	38.2	6.77	20	2.56	48	7.22	115	17	11	20	12	16	11	0.04	0.07	0.04	0.06	0.04	0.07
Rio Grande below Cochiti Dam, NM	5/3/21	1061926.2	353704.8	13.1	1.5	7.8	2.67	115	35.2	6.56	16.6	2.3	55	5.81	102	15	9	16	10	15	10	0.10	0.16	0.09	0.15	0.10	0.15
Rio Grande below Cochiti Dam, NM	8/9/21	1061926.2	353704.8	22.9	0.97	7.7	3.69	114	36.2	5.72	15.1	2.81	40.7	4.81	103	21	13	20	12	15	10	0.05	0.08	0.05	0.08	0.06	0.10
Rio Grande at San Felipe, NM	12/7/05	1062623.4	352640.5	3.5	1.1	8.5	1.69	123	39.4	6.1	17.2	2.68	33.6	5.57	223	16	10	20	12	17	11	0.07	0.11	0.06	0.09	0.06	0.10
Rio Grande at San Felipe, NM	12/7/05	1062623.4	352640.5	3.5	1.1	8.5	1.94	115	36.6	5.69	16.1	2.48	33.6	5.57	223	18	11	23	14	16	10	0.06	0.10	0.05	0.08	0.07	0.11
Rio Grande at San Felipe, NM	4/24/06	1062623.4	352640.5	11	1.5	8.3	1.34	114	35.3	6.27	18.3	2.61	36.4	5.92	223	12	8	13	8.1	16	10	0.12	0.20	0.12	0.19	0.09	0.15
Rio Grande at San Felipe, NM	8/14/06	1062623.4	352640.5	22.5	1.3	8.5	3.2	105	34.2	4.91	16.4	3.14	36.6	4.82	217	42	26	37	23	15	9.8	0.03	0.05	0.04	0.06	0.09	0.13

Location ID	Date	X	Y	Temp. (C)	Copper (µg/L)	pH	DOC (mg/L)	Hardness (mg/L CaCO^3)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Sulfate (mg/L)	Cl (mg/L)	Alkalinity (mg/L CaCO^3)	BLM (µg/L) Acute	BLM (µg/L) Chronic	MLR SSWQC (µg/L) Acute	MLR SSWQC (µg/L) Chronic	New Mexico Hardness-based Criteria (µg/L) Acute	New Mexico Hardness-based Criteria (µg/L) Chronic	BLM Acute TU	BLM Chronic TU	MLR SSWQC Acute TU	MLR SSWQC Chronic TU	New Mexico Hardness-based Criteria Acute TU	New Mexico Hardness-based Criteria Chronic TU
Rio Grande at San Felipe, NM	12/4/06	1062623.4	352640.5	3.5	0.82	8.3	1.37	104	32.6	5.54	16.3	2.52	33.2	4.79	198	11	7	13	8.3	15	9.7	0.07	0.12	0.06	0.10	0.05	0.08
Rio Grande at San Felipe, NM	5/3/07	1062623.4	352640.5	13	2.2	8.2	5.49	94.8	29.4	5.2	16.6	2.53	42.6	5.96	195	45	28	50	31	13	8.9	0.05	0.08	0.04	0.07	0.17	0.25
Rio Grande at San Felipe, NM	8/22/07	1062623.4	352640.5	21.5	1.2	8.2	6.63	118	37.2	6.2	18.8	3.07	43.6	4.93	222	65	40	62	38	16	11	0.02	0.03	0.02	0.03	0.08	0.11
Rio Grande at San Felipe, NM	11/12/08	1062623.4	352640.5	8	4.8	8.3	2.54	132	41.7	6.76	20	2.83	39.7	6.24	255	22	14	25	16	18	12	0.22	0.35	0.19	0.30	0.27	0.40
Rio Grande at Alameda Bridge at Alameda, NM	12/12/05	1063834	351151.8	2.5	1.5	8.3	1.58	140	44.9	6.81	25.3	3.28	44.1	11.6	255	14	8	16	9.7	19	12	0.11	0.18	0.09	0.15	0.08	0.13
Rio Grande at Alameda Bridge at Alameda, NM	4/25/06	1063834	351151.8	16	1.5	8.6	2.16	112	35.1	6.05	20	2.94	38.8	7.37	215	27	17	27	17	16	10	0.06	0.09	0.06	0.09	0.09	0.15
Rio Grande at Alameda Bridge at Alameda, NM	8/15/06	1063834	351151.8	22	1.6	8	2.97	360	126	11.1	83.2	7.47	398	44.7	194	31	19	24	15	47	28	0.05	0.08	0.07	0.11	0.03	0.06
Rio Grande at Alameda Bridge at Alameda, NM	12/5/06	1063834	351151.8	3	0.77	8.6	1.11	110	34.7	5.74	21.9	2.88	38.1	9.68	208	11	7	14	8.4	15	10	0.07	0.11	0.06	0.09	0.05	0.08
Rio Grande at Alameda Bridge at Alameda, NM	5/4/07	1063834	351151.8	14	1.6	8.1	4.35	98.7	31.3	5.01	24.6	3.18	45.9	11.8	193	35	22	36	22	14	9.2	0.05	0.07	0.04	0.07	0.11	0.17
Rio Grande at Alameda Bridge at Alameda, NM	8/23/07	1063834	351151.8	21	1.8	7.9	7.13	119	37.5	6.25	19.2	3.06	44.4	5.32	221	50	31	50	30	17	11	0.04	0.06	0.04	0.06	0.11	0.16
Rio Grande at Alameda Bridge at Alameda, NM	11/13/08	1063834	351151.8	7.5	1.9	8.4	2.44	138	44.1	6.98	26.7	3.49	44.9	12.9	273	24	15	27	16	19	12	0.08	0.13	0.07	0.12	0.10	0.16
Rio Grande at Alameda Bridge at Alameda, NM	5/20/09	1063834	351151.8	16	1.2	8.1	6.77	91.2	29.2	4.47	10.4	2.36	29.6	3.38	154	52	32	57	35	13	8.6	0.02	0.04	0.02	0.03	0.09	0.14
Rio Grande at Alameda Bridge at Alameda, NM	8/21/09	1063834	351151.8	24.5	0.85	8.6	3.04	119	38	5.81	17.1	2.79	45.4	5.18	202	47	29	38	23	16	11	0.02	0.03	0.02	0.04	0.05	0.08
Rio Grande at Alameda Bridge at Alameda, NM	11/23/09	1063834	351151.8	8.6	1	8.4	2.37	132	42.1	6.59	22.9	3.03	45.7	9.32	254	23	14	26	16	18	12	0.04	0.07	0.04	0.06	0.06	0.08
Rio Grande at Alameda Bridge at Alameda, NM	5/11/10	1063834	351151.8	13.6	0.87	8.2	4.7	94.5	30.3	4.59	13.7	2.26	33.9	5.42	172	39	24	43	26	13	8.9	0.02	0.04	0.02	0.03	0.07	0.10
Rio Grande at Alameda Bridge at Alameda, NM	8/17/10	1063834	351151.8	25.6	1.2	8.1	4.03	113	36	5.52	18.4	3.29	47.3	7.84	201	38	24	34	21	16	10	0.03	0.05	0.04	0.06	0.08	0.12
Rio Grande at Alameda Bridge at Alameda, NM	12/3/10	1063834	351151.8	5.9	0.5	8.4	1.96	138	43.7	7.12	26.9	3.46	47.8	12.7	258	19	12	21	13	19	12	0.03	0.04	0.02	0.04	0.03	0.04
Rio Grande at Alameda Bridge at Alameda, NM	6/3/11	1063834	351151.8	16.9	0.71	8.2	3.38	122	38.2	6.59	17.1	2.7	47.3	5.32	210	30	19	31	19	17	11	0.02	0.04	0.02	0.04	0.04	0.06
Rio Grande at Alameda Bridge at Alameda, NM	8/18/11	1063834	351151.8	27.9	0.81	8.1	3.86	104	32.3	5.57	14	2.99	37	3.86	186	37	23	32	20	14	9.6	0.02	0.03	0.03	0.04	0.06	0.08

Location ID	Date	X	Y	Temp. (C)	Copper (µg/L)	pH	DOC (mg/L)	Hardness (mg/L CaCO^{3})	Ca	Mg	Na	K	Sulfate	Cl	Alkalinity (mg/L CaCO^{3})	BLM (µg/L)		MLR SSWQC (µg/L)		New Mexico Hardness-based Criteria (µg/L)		BLM		MLR SSWQC		New Mexico Hardness-based Criteria	
									(mg/L)							Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute TU	Chronic TU	Acute TU	Chronic TU	Acute TU	Chronic TU
Rio Grande at Alameda Bridge at Alameda, NM	12/9/11	1063834	351151.8	3.2	0.8	8.1	2.53	119	37.2	6.29	17.8	2.89	35.8	6.49	223	18	11	21	13	16	11	0.04	0.07	0.04	0.06	0.05	0.07
Rio Grande at Alameda Bridge at Alameda, NM	4/26/12	1063834	351151.8	16	0.92	8.3	3.83	95.7	29.9	5.13	17.9	2.68	29.7	9.18	184	37	23	38	23	13	9	0.03	0.04	0.02	0.04	0.07	0.10
Rio Grande at Alameda Bridge at Alameda, NM	8/23/12	1063834	351151.8	23.5	1	8.2	4	131	42.1	6.54	17.5	3.75	43.3	4.82	226	41	26	37	23	18	12	0.02	0.04	0.03	0.04	0.06	0.08
Rio Grande at Alameda Bridge at Alameda, NM	12/20/12	1063834	351151.8	1.2	0.8	8.2	2.58	137	43.3	7.12	20.3	2.83	49.8	6.45	240	20	12	24	15	19	12	0.04	0.07	0.03	0.05	0.04	0.07
Rio Grande at Alameda Bridge at Alameda, NM	5/10/13	1063834	351151.8	16.3	0.8	8.1	2.35	124	38.1	7	21.3	2.87	54.5	6.1	231	20	12	20	12	17	11	0.04	0.07	0.04	0.07	0.05	0.07
Rio Grande at Alameda Bridge at Alameda, NM	8/2/13	1063834	351151.8	23.2	0.84	8.1	4.52	141	45.3	6.81	22.3	4.26	55.9	6.24	255	43	27	38	24	19	13	0.02	0.03	0.02	0.04	0.04	0.06
Rio Grande at Alameda Bridge at Alameda, NM	12/18/13	1063834	351151.8	4	1.8	8.2	2.77	135	42.5	7.07	26	3.44	49.9	12.1	252	22	14	25	16	19	12	0.08	0.13	0.07	0.11	0.09	0.15
Rio Grande at Alameda Bridge at Alameda, NM	5/13/14	1063834	351151.8	11.9	0.8	8.2	2.97	127	40.1	6.59	21.6	3.02	58.7	7.59	220	25	16	27	17	18	11	0.03	0.05	0.03	0.05	0.04	0.07
Rio Grande at Alameda Bridge at Alameda, NM	8/22/14	1063834	351151.8	21.4	1.2	8.2	3.21	123	39.9	5.71	17.8	3.76	40.7	22.6	220	32	20	29	18	17	11	0.04	0.06	0.04	0.07	0.07	0.11
Rio Grande at Alameda Bridge at Alameda, NM	1/7/15	1063834	351151.8	5.6	0.8	8.1	2.06	122	38.1	6.54	26	3.28	49.4	14.6	243	15	10	17	11	17	11	0.05	0.08	0.05	0.07	0.05	0.07
Rio Grande at Alameda Bridge at Alameda, NM	3/28/15	1063834	351151.8	12.8	1.6	7.5	3.53	98.6	30.9	5.23	20.7	3.06	32.5	10.4	212	15	9	15	9.3	14	9.2	0.11	0.18	0.11	0.17	0.11	0.17
Rio Grande at Alameda Bridge at Alameda, NM	5/26/16	1063834	351151.8	17.1	0.98	8	4.35	105	32.8	5.56	15.8	2.67	36.7	5.37	90.1	32	20	33	20	14	9	0.03	0.05	0.03	0.05	0.07	0.10
Rio Grande at Alameda Bridge at Alameda, NM	8/30/16	1063834	351151.8	23.8	1.9	8	2.98	114	37.5	4.8	17	2.88	50.7	6.09	98.4	24	15	23	14	15	10	0.08	0.13	0.08	0.14	0.12	0.19
Rio Grande at Alameda Bridge at Alameda, NM	12/14/16	1063834	351151.8	7.3	0.89	8.4	1.91	132	41.4	6.94	23	3.05	48.7	9.25	120	18	11	21	13	17	11	0.05	0.08	0.04	0.07	0.05	0.08
Rio Grande at Alameda Bridge at Alameda, NM	4/28/17	1063834	351151.8	11.6	1.2	7.9	4.84	90.8	28.5	4.71	12.6	2.12	33.9	5.07	77.9	29	18	33	20	12	8	0.04	0.07	0.04	0.06	0.10	0.15
Rio Grande at Alameda Bridge at Alameda, NM	8/18/17	1063834	351151.8	23.1	1.1	8.2	3.31	107	33.8	5.35	16.1	2.79	34.1	6.56	103	33	20	30	19	14	9	0.03	0.05	0.04	0.06	0.08	0.12
Rio Grande at Alameda Bridge at Alameda, NM	1/25/18	1063834	351151.8	1.7	0.59	8	1.98	126	39.8	6.39	27.5	3.11	45.5	15.2	118	14	9	15	9	17	11	0.04	0.07	0.04	0.06	0.04	0.05
Rio Grande at Alameda Bridge at Alameda, NM	4/13/18	1063834	351151.8	9.6	0.56	8.2	1.72	120	37.6	6.37	23	3.33	39.5	9.12	115	15	9	16	10	16	10	0.04	0.06	0.04	0.06	0.04	0.05

Location ID	Date	X	Y	Temp. (C)	Copper (µg/L)	pH	DOC (mg/L)	Hardness (mg/L CaCO^{3})	Ca (mg/L)	Mg	Na	K	Sulfate	Cl	Alkalinity (mg/L CaCO^{3})	BLM (µg/L)		MLR SSWQC (µg/L)		New Mexico Hardness-based Criteria (µg/L)		BLM		MLR SSWQC		New Mexico Hardness-based Criteria	
																Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute TU	Chronic TU	Acute TU	Chronic TU	Acute TU	Chronic TU
Rio Grande at Alameda Bridge at Alameda, NM	8/22/18	1063834	351151.8	22.9	1.1	7.9	3.1	118	37.7	5.71	14.9	2.6	54.9	4.69	103	22	14	21	13	16	10	0.05	0.08	0.05	0.08	0.07	0.11
Rio Grande at Alameda Bridge at Alameda, NM	2/28/19	1063834	351151.8	7.5	1.3	8.1	1.78	113	35.1	6.18	20.9	2.66	52.3	11.3	119	13	8	15	9	15	10	0.10	0.16	0.09	0.14	0.09	0.13
Rio Grande at Alameda Bridge at Alameda, NM	8/21/19	1063834	351151.8	22.3	0.92	8.3	2.82	82.5	26.2	4.06	10.6	2.46	21.2	3.39	79.6	29	18	28	17	11	8	0.03	0.05	0.03	0.05	0.08	0.12
Rio Grande at Alameda Bridge at Alameda, NM	1/15/20	1063834	351151.8	3.7	1.1	8.5	2.12	120	37.7	6.23	21.5	2.72	43.9	11.6	115	20	13	25	15	16	10	0.05	0.09	0.04	0.07	0.07	0.11
Rio Grande at Alameda Bridge at Alameda, NM	8/19/20	1063834	351151.8	23.9	2.8	8.5	3.1	136	42.9	6.94	20.3	3.07	61.3	7.23	108	44	27	37	22	18	12	0.06	0.10	0.08	0.12	0.16	0.24
Rio Grande at Alameda Bridge at Alameda, NM	1/11/21	1063834	351151.8	3.7	0.62	8.4	2.01	138	43.1	7.35	23.7	3.02	54.3	9.44	127	19	12	22	13	18	12	0.03	0.05	0.03	0.05	0.03	0.05
Rio Grande at Alameda Bridge at Alameda, NM	5/5/21	1063834	351151.8	14.3	0.91	8.3	2.82	122	37.4	6.73	20.3	2.67	56.3	8.61	106	27	17	28	17	16	11	0.03	0.05	0.03	0.05	0.06	0.09
Rio Grande at Alameda Bridge at Alameda, NM	8/11/21	1063834	351151.8	23.1	0.81	8.2	3.28	123	39.4	5.87	18.6	3.2	43.7	7.15	112	33	21	30	19	16	11	0.02	0.04	0.03	0.04	0.05	0.08

BLM – biotic ligand model
DOC – dissolved organic carbon
ID – identification
MLR – multiple linear regression
SSWQC – site-specific water quality criteria
TU – toxic unit
WQC – water quality criteria

D3 Rio Grande Silvery Minnow (*Hybognathus amarus*)

The Rio Grande silvery minnow (family *Cyprinidae*) is a small schooling fish species that lives in a restricted range of the Rio Grande in New Mexico between Cochiti Pueblo and Elephant Butte Reservoir. Historically, the range this species was larger; it has been fragmented by dams and degraded by various hydrologic modifications (USFWS 2021). Silvery minnow prefer large, warm, riverine habitat with low to moderate flows over relatively fine substrates. They are benthic feeders, consuming plant material and benthic invertebrates at the sediment-water interface.

As with the Rio Grande cutthroat trout, discussed above, adverse effects on minnow are not expected as a result of the proposed copper SSWQC. Adopting and implementing these criteria would provide a suitable level of protection for sensitive aquatic life (including minnow prey), and historical copper concentrations have not exceeded the proposed SSWQC (Table D-1). The EPA (2007) dataset contains toxicity data for other cyprinids that are less sensitive than salmonids (discussed above) and substantially less sensitive than aquatic invertebrates included in that dataset.

D4 New Mexico Jumping Mouse (*Zapus hudsonius luteus*)

The range of the New Mexico jumping mouse (*Zapus hudsonius luteus*) includes the Jemez, Sangre de Cristo, San Juan, White, and Sacramento Mountains of New Mexico, Arizona, and Colorado as well as riparian areas along the main stem of Rio Grande (USFWS 2020). This species generally inhabits elevations below 9,500 feet and is typically observed within close proximity to perennial streams. The jumping mouse hibernates from September or October to May or June with a limited active period. They are mainly active in summer months when riparian forb, sedge, and grass seeds are plentiful. Therefore, upon emergence from hibernation, jumping mice must breed, rear their young, and then accumulate sufficient fat reserves to sustain them through the next hibernation period all within a few months. While little research is available on jumping mouse hibernacula, what data are available suggest that jumping mice hibernate in small nests made of vegetation under shrubs or in underground burrows, typically close perennial water bodies.

Jumping mice primarily breed in July or August and likely only have one litter each year (USFWS 2020). Jumping mice use dense riparian herbaceous vegetation as shelter and food source, however females use areas outside the moist riparsian zone for giving birth and rearing young. Jumping mice most likely only have a life span of one to two years and are prey for snakes, foxes, weasels, and birds of prey.

It is not expected that the SSWQC would adversely impact the New Mexico jumping mouse. Jumping mice feed primarily on terrestrial plant matter and to a lesser extent on invertebrates (e.g., insects and snails) and fruit (USFWS 2020), and these dietary items would not be adversely impacted by a change in the copper WQC. Copper concentrations associated with the SSWQC are protective of fish and small aquatic invertebrate species; the potential for impacts in a larger mammalian species that is exposed to a far lesser degree (i.e., through water ingestion or dermal exposures), is expected to be very low.

D5 Mexican Spotted Owl (*Strix occidentalis lucida*)

The Mexican spotted owl occupies a broad geographic range which extends north from Aguascalientes, Mexico, throughout Arizona, New Mexico, Utah, Colorado, and into western Texas (Palumbo and Johnson 2015). The owl commonly occupies mixed-conifer forests, and the highest densities of owl occur in forests that have minimal human disturbance. Home ranges for Mexican spotted owl vary from about 260 to 1,500 hectares.

Mexican spotted owl consume a variety of terrestrial prey including small and medium sized rodents (e.g., woodrats, mice, and voles), bats, birds, and reptiles. Nesting habitats are in areas with complex forest structure or rocky canyons that contain mature or old growth conifer forests (Palumbo and Johnson 2015). Some Mexican spotted owls are year-round residents within an area and some move considerable distances, generally to more open habitat at lower elevations during the winter (Palumbo and Johnson 2010).

It is not expected that the Mexican spotted owl would be adversely affected by a change in copper WQC consistent with EPA's national recommended copper AWQC for aquatic life. They prey on small terrestrial mammals, birds, and reptiles rather than aquatic life. Exposures of owls to dissolved copper would be very limited; owls tend not to drink water (instead getting water through their diet) but may be dermally exposed periodically while bathing. Considering the relatively low potential (including frequency and duration) for exposure, the low potential for copper toxicity through a dermal route of exposure (and lack of a route through ingestion), and the relative insensitivity of large birds to copper exposures at what should be an acceptable level for small, sensitive aquatic life, it is concluded that Mexican spotted owl will not be affected by a change in the copper WQC.

D6 Southwestern Willow Flycatcher (*Empidonax traillii extimus*)

The southwestern willow flycatcher has a broad range across the southwest including California, Arizona, New Mexico, Colorado, Utah, and Nevada (Sogge et al. 2010). They breed in North America, but winter in the subtropical and tropical regions of southern Mexico, Central America, and northern South America. Breeding and nesting habitat is dense riparian vegetation (with tree and shrub cover) where there is surface water present or where soil moisture is high enough to maintain dense vegetation. Flycatcher habitat selection appears to be driven more by plant structure than by species composition; nests are placed where there is suitable twig and vegetative structure.

Flycatchers are insectivores and prey upon a variety of taxa including leafhoppers (Homoptera), dragonflies (Odonata), true bugs (Hemiptera), bees and wasps (Hymenoptera), and flies (Diptera) (Sogge et al. 2010). Flycatcher's diet may include species with an aquatic larval life stage. The copper BLM (and, by extension, the SSWQC) is not expected to adversely impact flycatcher dietary items; rather, the BLM is intended to be protective of aquatic life and should therefore be protective of flycatcher prey.

Flycatchers may directly ingest dissolved copper while drinking or bathing. As noted above, birds are less sensitive to copper than is aquatic life, so the copper BLM (and, by extension, the SSWQC) should also be protective of birds exposed dermally or through drinking and protective of potential prey bases for birds.

D7 Yellow-billed Cuckoo (*Coccyzus americanus*)

Historically, the yellow-billed cuckoo bred throughout most of continental North America, but currently it is only found in the southwest, Midwest, and eastern US and Canada (Wiggins 2005). Yellow-billed cuckoos winter in South America, mostly east of the Andes Mountains, only spending late spring and summer months in North America. In southwest regions cuckoos prefer to nest in riparian woodlands, particularly those with an intact understory. Nests are made in dense patches of broad-leaved deciduous trees close to water.

Yellow-billed cuckoos feed on insects including grasshoppers, crickets, and katydids (Orthoptera), caterpillars (Lepidoptera), true bugs (Hemiptera), and beetles (Coleoptera). Prey types change seasonally based on availability. However, because the BLM and SSWQC are intended to be protective of aquatic life, it is unlikely that cuckoo's prey would be adversely affected by copper exposures below the criteria.

D8 Jemez Mountains Salamander (*Plethodon neomexicanus*)

The Jemez Mountains Salamander is restricted to coniferous forests at elevations between approximately 7,000 and 11,000 ft in north-central New Mexico (78 FR 69569), including the Jemez Mountains in Los Alamos, Rio Arriba, and Sandoval Counties and around Valles Caldera National Preserve (primarily along the rim of the collapsed caldera with some occurring within the caldera) (Ramotik and Scott 1988).

The Jemez Mountains salamander is strictly terrestrial and does not use standing water for any life stage (78 FR 55600). They spend much of their life underground but emerge when conditions are warm and wet, typically from July through September. Aboveground activity usually occurs under decaying logs, rocks, bark, or moss mats. Salamanders prey on ants (e.g., Hymenoptera and Formicidae), mites (Acari), and beetles (Coleoptera). While reproduction in the wild has not been observed, based on the laboratory setting, mating is believed to occur between July and August during the summer monsoon season. Eggs are thought to be laid underground, and fully formed salamanders hatch from the eggs; there is no tadpole life stage that would be subject to waterborne exposure.

Because they are limited to terrestrial habitat and prey, the use of the SSWQC is not expected to adversely affect the Jemez Mountain salamander directly or indirectly (through diet or habitat alteration). It is assumed that Jemez Mountain salamander, like other salamander species, absorb moisture from their environment rather than drinking water from streams; therefore, this species would not be exposed to dissolved copper levels related to the SSWQC.

D9 References

EPA. 2007. Aquatic life ambient freshwater quality criteria - copper, 2007 revision. EPA-822-R-07-001. Office of Water, US Environmental Protection Agency Washington, DC.

EPA. 1985. Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses. PB85-227049. Office of Research and Development, US Environmental Protection Agency, Washington, DC.

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Wiggins DA. 2005. Yellow-billed cuckoo (*Coccyzus americanus*): a technical conservation assessment. Prepared for the USDA Forest Service, Rocky Mountain Region, Species Conservation Project. Strix Ecological Research, Oklahoma City, OK.

Windward. 2018. Data-quality objectives and data quality assessment: application of the biotic ligand model to generate water quality criteria for four metals in surface waters of the Pajarito Plateau New Mexico. Windward Environmental LLC, Seattle, WA.

ENCLOSURE 2

Response to Comments on N3B's Draft Copper Criteria for the Pajarito Plateau Report, Provided by Communities for Clean Water, Dated November 9, 2023

Response to *Comments on N3B's Draft Copper Criteria for the Pajarito Plateau Report*, Provided by Communities For Clean Water Dated November 9, 2023

INTRODUCTION

To facilitate review of this response, the Communities for Clean Water's (CCW's) comments are included verbatim. The U.S. Department of Energy (DOE) Environmental Management Los Alamos Field Office responses follow each CCW comment.

SPECIFIC COMMENTS

CCW Comment

1. ***Aggregation of Data:** The proposed site-specific water quality criteria for copper creates a multi-linear regression based on an aggregate of data across the Pajarito Plateau watershed – a 43 square mile area that encompasses nine major watersheds.*

   EM-LA/N3B should conduct an analysis to demonstrate that there is no substantial difference in site specific criteria between the major watersheds (i.e., Sandia vs Mortandad) and developed and undeveloped watersheds.

DOE Response

1. Just as the hardness-based and biotic ligand model (BLM) copper criteria vary according to water chemistry, so will the multiple linear regression- (MLR-) based copper site-specific water quality criteria (SSWQC). If there are significant differences in water chemistry between watersheds (or in developed versus undeveloped portions of the same watershed), then it's reasonable to expect respective differences in SSWQC values. Protectiveness of the SSWQC, however, would be the same regardless of water quality condition. The SSWQC (or the hardness-based criteria or BLM) varies with water quality because bioavailability and toxicity also vary in response to water chemistry. For example, Los Alamos National Laboratory's (LANL's) Individual Permit currently includes watershed-specific target action levels for copper, which vary according to watershed-specific average hardness. Therefore, the evaluation CCW proposes would neither support nor invalidate the appropriateness of the SSWQC.

   The demonstration report already includes a detailed discussion (particularly in Section 5.4 and Appendix B) of the statistical evaluations conducted to date that show how stream hydrology and other watershed factors were considered when developing the MLR-based SSWQC. Ultimately, we selected a three-parameter MLR (with a squared pH term) without watershed-specific features. We found that the model was not meaningfully improved by adding more parameters (hydrology, land use, fire, etc.). For example, Table 5-4 presents the statistical outcome of various models that considered hydrology; including hydrology as a feature improved predictive accuracy by 0.2%.

CCW Comment

2. ***Clarity between BLM and MLR:*** ***Some sections of the report, particularly towards the beginning of the document, still misrepresent the use of the Biotic Ligand Model (BLM) vs Multiple Linear Regression (MLR) (e.g., page 20).***

The report is still referring to the method used as "BLM" when really it is an MLR approach. Please update references throughout and submit a new version to the NMED Surface Water Quality Bureau, the N3B website, and provide and electronic notice to the public.

DOE Response

2. To be responsive to this comment, we have reviewed the document and attempted to shift the emphasis originally placed on the BLM to the MLR. For example, the first sentence in Section 4 calls the SSWQC "MLR-based," and Section 4.3 describes the use of MLR. However, keeping ample discussion and reference to the BLM remains integral to the discussion of the MLR because the BLM is the underlying basis for the MLR:

   - Many of the samples in the dataset were collected and analyzed for the purpose calculating BLM criteria.
   - The full dataset, which includes some estimated parameter values, was aggregated with the specific purpose of using the BLM.
   - The MLR dataset (Appendix A) includes BLM outputs (not just inputs).
   - BLM outputs were used as the dependent variable in the MLR equation.

   The purpose of the MLR is to estimate BLM outputs (i.e., EPA's recommended criteria) using 3 water quality inputs (pH, DOC, and hardness) rather than the 12 default inputs required by the BLM. Because of the high degree of accuracy of the MLR for predicting BLM output, the copper SSWQC are consistent with the BLM. Throughout the report, we emphasize that the MLR provides an accurate estimate of the BLM, which we rigorously demonstrate in the report; we never conflate the two models.

   CCW mentions page 20 as an example where the BLM is mentioned. In this instance, we only find mention of "BLM data," by which we mean the dataset of water-quality inputs to the BLM. Because these data were input into the BLM to generate outputs used in the MLR development, this terminology is accurate and appropriate as currently used.

CCW Comment

3. ***Rationale For Removing Samples from the Modeling:*** ***Please clarify the number of stormwater samples removed from the modeling dataset as briefly described on page B-5 and B-6.***

The text implies that 94 stormwater samples were removed. CCW requests that the rationale for what samples were used and what samples were removed be more clearly defined and explained in the new version of the report.

DOE Response

3. Section B2.2 provides a discussion of the stepwise compilation of data, including methods for estimating water chemistry data, as appropriate and based on regulatory guidance, to establish a highly robust dataset. This involved excluding samples where DOC was neither measured nor could be estimated, those that lacked pH data, and/or those where other ions could not be estimated or that do not have reasonable default values (e.g., from EPA [2007] copper BLM guidance). This step in the aggregation process resulted in a dataset with 611 samples.

   Section B2.3 discusses the reduction of this dataset from 611 to 517 samples (the difference being the 94 samples that CCW references in their comment) and provides the reasons that the dataset was further reduced:

   1) 4 duplicate (redundant) entries were observed in the dataset and reduced to single entries.

   2) 76 stormwater discharge samples, representing “end-of-pipe” or runoff samples of stormwater, were identified and removed, so that the BLM dataset only includes ambient water samples.

   3) 14 samples were removed that had pH, DOC, or hardness measurements outside of the BLM’s prescribed (calibrated) range.

   In total, this amounts to 94 samples excluded, per available EPA guidance.

   The remaining 517-sample dataset includes only:

   1) samples with the complete set of BLM parameters;

   2) unique sampling events and measurements;

   3) ambient (i.e., instream) samples; and

   4) samples with BLM parameters within prescribed calibration ranges, meaning that no extrapolation was required to develop the MLR.

CCW Comment

4. ***<u>Please provide Appendix A:</u> CCW requests a copy via flash drive of Appendix A (BLM Dataset for Pajarito Plateau Surface Waters).***

   The requested data can be mailed to CCW c/o Amigos Bravos, P.O. Box 238, Taos, NM 87571.

DOE Response

4. Appendix A will be uploaded to the Electronic Public Reading Room as an Excel file with the final Demonstration Report.

REFERENCE

EPA. 2007. Aquatic life ambient freshwater quality criteria - copper, 2007 revision. EPA-822-R-07-001. Office of Water, US Environmental Protection Agency Washington, DC.

EXHIBIT F

TITLE 20 ENVIRONMENTAL PROTECTION
CHAPTER 6 WATER QUALITY
PART 4 STANDARDS FOR INTERSTATE AND INTRASTATE SURFACE WATERS

20.6.4.1 ISSUING AGENCY: Water Quality Control commission.
[20.6.4.1 NMAC - Rp 20 NMAC 6.1.1001, 10/12/2000]

20.6.4.2 SCOPE: Except as otherwise provided by statute or regulation of the water quality control commission, this part governs all surface waters of the state of New Mexico, which are subject to the New Mexico Water Quality Act, Sections 74-6-1 through 74-6-17 NMSA 1978.
[20.6.4.2 NMAC - Rp 20 NMAC 6.1.1002, 10/12/2000; A, 5/23/2005]

20.6.4.3 STATUTORY AUTHORITY: This part is adopted by the water quality control commission pursuant to Subsection C of Section 74-6-4 NMSA 1978.
[20.6.4.3 NMAC - Rp 20 NMAC 6.1.1003, 10/12/2000]

20.6.4.4 DURATION: Permanent.
[20.6.4.4 NMAC - Rp 20 NMAC 6.1.1004, 10/12/2000]

20.6.4.5 EFFECTIVE DATE: October 12, 2000, unless a later date is indicated in the history note at the end of a section.
[20.6.4.5 NMAC - Rp 20 NMAC 6.1.1005, 10/12/2000]

20.6.4.6 OBJECTIVE:

A. The purpose of this part is to establish water quality standards that consist of the designated use or uses of surface waters of the state, the water quality criteria necessary to protect the use or uses and an antidegradation policy.

B. The state of New Mexico is required under the New Mexico Water Quality Act (Subsection C of Section 74-6-4 NMSA 1978) and the federal Clean Water Act, as amended (33 U.S.C. Section 1251 *et seq*.) to adopt water quality standards that protect the public health or welfare, enhance the quality of water and are consistent with and serve the purposes of the New Mexico Water Quality Act and the federal Clean Water Act. It is the objective of the federal Clean Water Act to restore and maintain the chemical, physical and biological integrity of the nation's waters, including those in New Mexico. This part is consistent with Section 101(a)(2) of the federal Clean Water Act, which declares that it is the national goal that wherever attainable, an interim goal of water quality that provides for the protection and propagation of fish, shellfish and wildlife and provides for recreation in and on the water be achieved by July 1, 1983. Agricultural, municipal, domestic and industrial water supply are other essential uses of New Mexico's surface water; however, water contaminants resulting from these activities will not be permitted to lower the quality of surface waters of the state below that required for protection and propagation of fish, shellfish and wildlife and recreation in and on the water, where practicable.

C. Pursuant to Subsection A of Section 74-6-12 NMSA 1978, this part does not grant to the water quality control commission or to any other entity the power to take away or modify property rights in water.

D. These surface water quality standards serve to respond to the inherent threats of climate change and provide resiliency for the continued protection and enhancement of water quality.
[20.6.4.6 NMAC - Rp 20 NMAC 6.1.1006, 10/12/2000; A, 5/23/2005; A, 4/23/2022]

20.6.4.7 DEFINITIONS: Terms defined in the New Mexico Water Quality Act, but not defined in this part will have the meaning given in the Water Quality Act.

A. Terms beginning with numerals or the letter "A," and abbreviations for units.

(1) "4Q3" means the critical low flow as determined by the minimum average flow over four consecutive days that occurs with a frequency of once in three years.

(2) "4T3 temperature" means the temperature not to be exceeded for four or more consecutive hours in a 24-hour period on more than three consecutive days.

(3) "6T3 temperature" means the temperature not to be exceeded for six or more consecutive hours in a 24-hour period on more than three consecutive days.

(4) Abbreviations used to indicate units are defined as follows:

PETITIONERS' EXHIBIT 2

(a) **"cfu/100 mL"** means colony-forming units per 100 milliliters; the results for *E. coli* may be reported as either colony forming units (CFU) or the most probable number (MPN), depending on the analytical method used;

(b) **"cfs"** means cubic feet per second;

(c) **"µg/L"** means micrograms per liter, equivalent to parts per billion when the specific gravity of the solution equals 1.0;

(d) **"µS/cm"** means microsiemens per centimeter; one µS/cm is equal to one µmho/cm;

(e) **"mg/kg"** means milligrams per kilogram, equivalent to parts per million;

(f) **"mg/L"** means milligrams per liter, equivalent to parts per million when the specific gravity of the solution equals 1.0;

(g) **"MPN/100 mL"** means most probable number per 100 milliliters; the results for *E. coli* may be reported as either CFU or MPN, depending on the analytical method used;

(h) **"NTU"** means nephelometric turbidity unit;

(i) **"pCi/L"** means picocuries per liter;

(j) **"pH"** means the measure of the acidity or alkalinity and is expressed in standard units (su).

(5) **"Acute toxicity"** means toxicity involving a stimulus severe enough to induce a response in 96 hours of exposure or less. Acute toxicity is not always measured in terms of lethality, but may include other toxic effects that occur within a short time period.

(6) **"Adjusted gross alpha"** means the total radioactivity due to alpha particle emission as inferred from measurements on a dry sample, including radium-226, but excluding radon-222 and uranium. Also excluded are source, special nuclear and by-product material as defined by the Atomic Energy Act of 1954.

(7) **"Aquatic life"** means any plant or animal life that uses surface water as primary habitat for at least a portion of its life cycle, but does not include avian or mammalian species.

(8) **"Attainable Use"** means a use that is achievable by the imposition of effluent limits required under sections 301(b) and 306 of the federal Clean Water Act and implementation of cost-effective and reasonable best management practices for nonpoint source control. An attainable use may or may not have criteria as stringent as the criteria for the designated use.

B. **Terms beginning with the letter "B".**

(1) **"Best management practices" or "BMPs":**

(a) for national pollutant discharge elimination system (NPDES) permitting purposes means schedules of activities, prohibitions of practices, maintenance procedures and other management practices to prevent or reduce the pollution of "waters of the United States;" BMPs also include treatment requirements, operating procedures and practices to control plant site runoff, spillage or leaks, sludge or waste disposal or drainage from raw material storage; or

(b) for nonpoint source pollution control purposes means methods, measures or practices selected by an agency to meet its nonpoint source control needs; BMPs include but are not limited to structural and nonstructural controls and operation and maintenance procedures; BMPS can be applied before, during and after pollution-producing activities to reduce or eliminate the introduction of pollutants into receiving waters; BMPs for nonpoint source pollution control purposes shall not be mandatory except as required by state or federal law.

(2) **"Bioaccumulation"** refers to the uptake and retention of a substance by an organism from its surrounding medium and food.

(3) **"Bioaccumulation factor"** is the ratio of a substance's concentration in tissue versus its concentration in ambient water, in situations where the organism and the food chain are exposed.

(4) **"Biomonitoring"** means the use of living organisms to test the suitability of effluents for discharge into receiving waters or to test the quality of surface waters of the state.

C. **Terms beginning with the letter "C".**

(1) **"CAS number"** means an assigned number by chemical abstract service (CAS) to identify a substance. CAS numbers index information published in chemical abstracts by the American chemical society.

(2) **"Chronic toxicity"** means toxicity involving a stimulus that lingers or continues for a relatively long period relative to the life span of an organism. Chronic effects include, but are not limited to, lethality, growth impairment, behavioral modifications, disease and reduced reproduction.

(3) **"Classified water of the state"** means a surface water of the state, or reach of a surface water of the state, for which the commission has adopted a segment description and has designated a use or uses and applicable water quality criteria in 20.6.4.101 through 20.6.4.899 NMAC.

(4) **"Climate change"** refers to any significant change in the measures of climate lasting for an extended period of time, typically decades or longer, and includes major changes in temperature, precipitation, wind patterns or other weather-related effects.

(5) **"Closed basin"** is a basin where topography prevents the surface outflow of water and water escapes by evapotranspiration or percolation.

(6) **"Coldwater"** in reference to an aquatic life use means a surface water of the state where the water temperature and other characteristics are suitable for the support or propagation or both of coldwater aquatic life.

(7) **"Coolwater"** in reference to an aquatic life use means the water temperature and other characteristics are suitable for the support or propagation of aquatic life whose physiological tolerances are intermediate between and may overlap those of warm and coldwater aquatic life.

(8) **"Commission"** means the New Mexico water quality control commission.

(9) **"Criteria"** are elements of state water quality standards, expressed as constituent concentrations, levels or narrative statements, representing a quality of water that supports a use. When criteria are met, water quality will protect the designated use.

D. **Terms beginning with the letter "D".**

(1) **"DDT and derivatives"** means 4,4'-DDT (CAS number 50293), 4,4'-DDE (CAS number 72559) and 4,4'-DDD (CAS number 72548).

(2) **"Department"** means the New Mexico environment department.

(3) **"Designated use"** means a use specified in 20.6.4.97 through 20.6.4.899 NMAC for a surface water of the state whether or not it is being attained.

(4) **"Dissolved"** refers to the fraction of a constituent of a water sample that passes through a 0.45-micrometer pore-size filter. The "dissolved" fraction is also termed "filterable residue."

(5) **"Domestic water supply"** means a surface water of the state that could be used for drinking or culinary purposes after disinfection.

E. **Terms beginning with the letter "E".**

(1) **"E. coli"** means the bacteria Escherichia coli.

(2) **"Emerging contaminants"** refer to water contaminants that may cause significant ecological or human health effects at low concentrations. Emerging contaminants are generally chemical compounds recognized as having deleterious effects at environmental concentrations whose negative impacts have not been fully quantified and may not have regulatory numeric criteria.

(3) **"Ephemeral"** when used to describe a surface water of the state means the water body contains water briefly only in direct response to precipitation; its bed is always above the water table of the adjacent region.

(4) **"Existing use"** means a use actually attained in a surface water of the state on or after November 28, 1975, whether or not it is a designated use.

F. **Terms beginning with the letter "F".**

(1) **"Fish culture"** means production of coldwater or warmwater fishes in a hatchery or rearing station.

(2) **"Fish early life stages"** means the egg and larval stages of development of fish ending when the fish has its full complement of fin rays and loses larval characteristics.

G. **Terms beginning with the letter "G"** [**RESERVED**]

H. **Terms beginning with the letter "H".**

(1) **"Hardness"** means the measure of dissolved calcium and magnesium salts in water expressed in units of dissolved calcium carbonate ($CaCO_3$) concentration unless otherwise noted.

(2) **"Harmonic mean flow"** is the number of daily flow measurements divided by the sum of the reciprocals of the flows; that is, it is the reciprocal of the arithmetic mean of reciprocal daily flow measurements consistent with the equations in Paragraph (1) of Subsection B of 20.6.4.11 NMAC.

(3) **"High quality coldwater"** in reference to an aquatic life use means a perennial surface water of the state in a minimally disturbed condition with considerable aesthetic value and superior coldwater aquatic life habitat. A surface water of the state to be so categorized must have water quality, stream bed characteristics and other attributes of habitat sufficient to protect and maintain a propagating coldwater aquatic life population.

(4) **"Human health-organism only"** means the health of humans who ingest fish or other aquatic organisms from waters that contain pollutants.

I. Terms beginning with the letter "I".

(1) **"Industrial water supply"** means the use or storage of water by a facility for process operations unless the water is supplied by a public water system. Industrial water supply does not include irrigation or other agricultural uses.

(2) **"Intermittent"** when used to describe a surface water of the state means the water body contains water for extended periods only at certain times of the year, such as when it receives seasonal flow from springs or melting snow.

(3) **"Interstate waters"** means all surface waters of the state that cross or form a part of the border between states.

(4) **"Intrastate waters"** means all surface waters of the state that are not interstate waters.

(5) **"Irrigation"** means application of water to land areas to supply the water needs of beneficial plants.

(6) **"Irrigation storage"** means storage of water to supply the needs of beneficial plants.

J. Terms beginning with the letter "J". [**RESERVED**]

K. Terms beginning with the letter "K". [**RESERVED**]

L. Terms beginning with the letter "L".

(1) **"LC-50"** means the concentration of a substance that is lethal to fifty percent of the test organisms within a defined time period. The length of the time period, which may vary from 24 hours to one week or more, depends on the test method selected to yield the information desired.

(2) **"Limited aquatic life"** as a designated use, means the surface water is capable of supporting only a limited community of aquatic life. This subcategory includes surface waters that support aquatic species selectively adapted to take advantage of naturally occurring rapid environmental changes, low-flow, high turbidity, fluctuating temperature, low dissolved oxygen content or unique chemical characteristics.

(3) **"Livestock watering"** means the use of a surface water of the state as a supply of water for consumption by livestock.

M. Terms beginning with the letter "M".

(1) **"Marginal coldwater"** in reference to an aquatic life use means that natural habitat conditions severely limit maintenance of a coldwater aquatic life population during at least some portion of the year or historical data indicate that the temperature of the surface water of the state may exceed that which could continually support aquatic life adapted to coldwater.

(2) **"Marginal warmwater"** in reference to an aquatic life use means natural intermittent or low flow or other natural habitat conditions severely limit the ability of the surface water of the state to sustain a natural aquatic life population on a continuous annual basis; or historical data indicate that natural water temperature routinely exceeds 32.2°C (90°F).

(3) **"Maximum temperature"** means the instantaneous temperature not to be exceeded at any time.

(4) **"Minimum quantification level"** means the minimum quantification level for a constituent determined by official published documents of the United States environmental protection agency.

N. Terms beginning with the letter "N".

(1) **"Natural background"** means that portion of a pollutant load in a surface water resulting only from non-anthropogenic sources. Natural background does not include impacts resulting from historic or existing human activities.

(2) **"Natural causes"** means those causal agents that would affect water quality and the effect is not caused by human activity but is due to naturally occurring conditions.

(3) **"Nonpoint source"** means any source of pollutants not regulated as a point source that degrades the quality or adversely affects the biological, chemical or physical integrity of surface waters of the state.

O. Terms beginning with the letter "O".

(1) **"Organoleptic"** means the capability to produce a detectable sensory stimulus such as odor or taste.

(2) **"Oversight agency"** means a state or federal agency, such as the United States department of agriculture forest service, that is responsible for land use or water quality management decisions affecting nonpoint source discharges where an outstanding national resource water is located.

P. Terms beginning with the letter "P".

(1) **"Playa"** means a shallow closed basin lake typically found in the high plains and deserts.

(2) **"Perennial"** when used to describe a surface water of the state means the water body typically contains water throughout the year and rarely experiences dry periods.

(3) **"Persistent toxic pollutants"** means pollutants, generally organic, that are resistant to environmental degradation through chemical, biological and photolytic processes and can bioaccumulate in organisms, causing adverse impacts on human health and aquatic life.

(4) **"Point source"** means any discernible, confined and discrete conveyance from which pollutants are or may be discharged into a surface water of the state, but does not include return flows from irrigated agriculture.

(5) **"Practicable"** means that which may be done, practiced or accomplished; that which is performable, feasible, possible.

(6) **"Primary contact"** means any recreational or other water use in which there is prolonged and intimate human contact with the water, such as swimming and water skiing, involving considerable risk of ingesting water in quantities sufficient to pose a significant health hazard. Primary contact also means any use of surface waters of the state for cultural, religious or ceremonial purposes in which there is intimate human contact with the water, including but not limited to ingestion or immersion, that could pose a significant health hazard.

(7) **"Public water supply"** means the use or storage of water to supply a public water system as defined by New Mexico's Drinking Water Regulations, 20.7.10 NMAC. Water provided by a public water system may need to undergo treatment to achieve drinking water quality.

Q. **Terms beginning with the letter "Q".** [**RESERVED**]

R. **Terms beginning with the letter "R".** [**RESERVED**]

S. **Terms beginning with the letter "S".**

(1) **"Secondary contact"** means any recreational or other water use in which human contact with the water may occur and in which the probability of ingesting appreciable quantities of water is minimal, such as fishing, wading, commercial and recreational boating and any limited seasonal contact.

(2) **"Segment"** means a classified water of the state described in 20.6.4.101 through 20.6.4.899 NMAC. The water within a segment should have the same uses, similar hydrologic characteristics or flow regimes, and natural physical, chemical and biological characteristics and exhibit similar reactions to external stresses, such as the discharge of pollutants.

(3) **"Specific conductance"** is a measure of the ability of a water solution to conduct an electrical current.

(4) **"State"** means the state of New Mexico.

(5) **"Surface water(s) of the state"**

(a) means all surface waters situated wholly or partly within or bordering upon the state, including the following:

(i) lakes;
(ii) rivers;
(iii) streams (including intermittent and ephemeral streams);
(iv) mudflats;
(v) sandflats;
(vi) wetlands;
(vii) sloughs;
(viii) prairie potholes;
(ix) wet meadows;
(x) playa lakes;
(xi) reservoirs; and
(xii) natural ponds.

(b) also means all tributaries of such waters, including adjacent wetlands, any manmade bodies of water that were originally created in surface waters of the state or resulted in the impoundment of surface waters of the state, and any "waters of the United States" as defined under the Clean Water Act that are not included in the preceding description.

(c) does not include private waters that do not combine with other surface or subsurface water or any water under tribal regulatory jurisdiction pursuant to Section 518 of the Clean Water Act. Waste treatment systems, including treatment ponds or lagoons designed and actively used to meet requirements of the Clean Water Act (other than cooling ponds as defined in 40 CFR Part 423.11(m) that also meet the criteria of this definition), are not surface waters of the state, unless they were originally created in surface waters of the state or resulted in the impoundment of surface waters of the state.

T. Terms beginning with the letter "T".

(1) "TDS" means total dissolved solids, also termed "total filterable residue."

(2) "Toxic pollutant" means those pollutants, or combination of pollutants, including disease-causing agents, that after discharge and upon exposure, ingestion, inhalation or assimilation into any organism, either directly from the environment or indirectly by ingestion through food chains, will cause death, shortened life spans, disease, adverse behavioral changes, reproductive or physiological impairment or physical deformations in such organisms or their offspring.

(3) "Tributary" means a perennial, intermittent or ephemeral waterbody that flows into a larger waterbody, and includes a tributary of a tributary.

(4) "Turbidity" is an expression of the optical property in water that causes incident light to be scattered or absorbed rather than transmitted in straight lines.

U. Terms beginning with the letter "U".

(1) "Unclassified waters of the state" means those surface waters of the state not identified in 20.6.4.101 through 20.6.4.899 NMAC.

(2) "Use attainability analysis" means a scientific study conducted for the purpose of assessing the factors affecting the attainment of a use.

V. Terms beginning with the letter "V" [**RESERVED**]

W. Terms beginning with the letter "W".

(1) "Warmwater" with reference to an aquatic life use means that water temperature and other characteristics are suitable for the support or propagation or both of warmwater aquatic life.

(2) "Water contaminant" means any substance that could alter if discharged or spilled the physical, chemical, biological or radiological qualities of water. "Water contaminant" does not mean source, special nuclear or by-product material as defined by the Atomic Energy Act of 1954, but may include all other radioactive materials, including but not limited to radium and accelerator-produced isotopes.

(3) "Water pollutant" means a water contaminant in such quantity and of such duration as may with reasonable probability injure human health, animal or plant life or property, or to unreasonably interfere with the public welfare or the use of property.

(4) "Wetlands" means those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions in New Mexico. Wetlands that are constructed outside of a surface water of the state for the purpose of providing wastewater treatment and that do not impound a surface water of the state are not included in this definition.

(5) "Wildlife habitat" means a surface water of the state used by plants and animals not considered as pathogens, vectors for pathogens or intermediate hosts for pathogens for humans or domesticated livestock and plants.

X. Terms beginning with the letters "X" through "Z". [**RESERVED**]

[20.6.4.7 NMAC - Rp 20 NMAC 6.1.1007, 10/12/2000; A, 7/19/2001; A, 5/23/2005; A, 7/17/2005; A, 8/1/2007; A, 12/1/2010; A, 1/14/2011; A, 3/2/2017; A, 4/23/2022]

20.6.4.8 ANTIDEGRADATION POLICY AND IMPLEMENTATION PLAN:

A. Antidegradation Policy: This antidegradation policy applies to all surface waters of the state.

(1) Existing uses, as defined in Paragraph (4) of Subsection E of 20.6.4.7 NMAC, and the level of water quality necessary to protect the existing uses shall be maintained and protected in all surface waters of the state.

(2) Where the quality of a surface water of the state exceeds levels necessary to support the propagation of fish, shellfish, and wildlife, and recreation in and on the water, that quality shall be maintained and protected unless the commission finds, after full satisfaction of the intergovernmental coordination and public participation provisions of the state's continuing planning process, that allowing lower water quality is necessary to accommodate important economic and social development in the area in which the water is located. In allowing such degradation or lower water quality, the state shall assure water quality adequate to protect existing uses fully. Further, the state shall assure that there shall be achieved the highest statutory and regulatory requirements for all new and existing point sources and all cost-effective and reasonable BMPs for nonpoint source control. Additionally, the state shall encourage the use of watershed planning as a further means to protect surface waters of the state.

(3) No degradation shall be allowed in waters designated by the commission as outstanding national resource waters (ONRWs), except as provided in Subparagraphs (a) through (e) of this paragraph and in Paragraph (4) of this Subsection A.

(a) After providing a minimum 30-day public review and comment period, the commission determines that allowing temporary and short-term degradation of water quality is necessary to accommodate public health or safety activities in the area in which the ONRW is located. Examples of public health or safety activities include but are not limited to replacement or repair of a water or sewer pipeline or a roadway bridge. In making its decision, the commission shall consider whether the activity will interfere with activities implemented to restore or maintain the chemical, physical or biological integrity of the water. In approving the activity, the commission shall require that:

(i) the degradation shall be limited to the shortest possible time and shall not exceed six months;

(ii) the degradation shall be minimized and controlled by best management practices or in accordance with permit requirements as appropriate; all practical means of minimizing the duration, magnitude, frequency and cumulative effects of such degradation shall be utilized;

(iii) the degradation shall not result in water quality lower than necessary to protect any existing use in the ONRW; and

(iv) the degradation shall not alter the essential character or special use that makes the water an ONRW.

(b) Prior to the commission making a determination, the department or appropriate oversight agency shall provide a written recommendation to the commission. If the commission approves the activity, the department or appropriate oversight agency shall oversee implementation of the activity.

(c) Where an emergency response action that may result in temporary and short-term degradation to an ONRW is necessary to mitigate an immediate threat to public health or safety, the emergency response action may proceed prior to providing notification required by Subparagraph (a) of this paragraph in accordance with the following:

(i) only actions that mitigate an immediate threat to public health or safety may be undertaken pursuant to this provision; non-emergency portions of the action shall comply with the requirements of Subparagraph (a) of this paragraph;

(ii) the discharger shall make best efforts to comply with requirements (i) through (iv) of Subparagraph (a) of this paragraph;

(iii) the discharger shall notify the department of the emergency response action in writing within seven days of initiation of the action;

(iv) within 30 days of initiation of the emergency response action, the discharger shall provide a summary of the action taken, including all actions taken to comply with requirements (i) through (iv) of Subparagraph (a) of this paragraph.

(d) Preexisting land-use activities, including grazing, allowed by federal or state law prior to designation as an ONRW, and controlled by best management practices (BMPs), shall be allowed to continue so long as there are no new or increased discharges resulting from the activity after designation of the ONRW.

(e) Acequia operation, maintenance, and repairs are not subject to new requirements because of ONRW designation. However, the use of BMPs to minimize or eliminate the introduction of pollutants into receiving waters is strongly encouraged.

(4) This antidegradation policy does not prohibit activities that may result in degradation in surface waters of the state when such activities will result in restoration or maintenance of the chemical, physical or biological integrity of the water.

(a) For ONRWs, the department or appropriate oversight agency shall review on a case-by-case basis discharges that may result in degradation from restoration or maintenance activities, and may approve such activities in accordance with the following:

(i) the degradation shall be limited to the shortest possible time;

(ii) the degradation shall be minimized and controlled by best management practices or in accordance with permit requirements as appropriate, and all practical means of minimizing the duration, magnitude, frequency and cumulative effects of such degradation shall be utilized;

(iii) the degradation shall not result in water quality lower than necessary to protect any existing use of the surface water; and

(iv) the degradation shall not alter the essential character or special use that makes the water an ONRW.

(b) For surface waters of the state other than ONRWs, the department shall review on a case-by-case basis discharges that may result in degradation from restoration or maintenance activities, and may approve such activities in accordance with the following:

(i) the degradation shall be limited to the shortest possible time;

(ii) the degradation shall be minimized and controlled by best management practices or in accordance with permit requirements as appropriate, and all practical means of minimizing the duration, magnitude, frequency and cumulative effects of such degradation shall be utilized; and

(iii) the degradation shall not result in water quality lower than necessary to protect any existing use of the surface water.

(5) In those cases where potential water quality impairment associated with a thermal discharge is involved, this antidegradation policy and implementing method shall be consistent with Section 316 of the federal Clean Water Act.

(6) In implementing this section, the commission through the appropriate regional offices of the United States environmental protection agency will keep the administrator advised and provided with such information concerning the surface waters of the state as he or she will need to discharge his or her responsibilities under the federal Clean Water Act.

B. Implementation Plan: The department, acting under authority delegated by the commission, implements the water quality standards, including the antidegradation policy, by describing specific methods and procedures in the continuing planning process and by establishing and maintaining controls on the discharge of pollutants to surface waters of the state. The steps summarized in the following paragraphs, which may not all be applicable in every water pollution control action, list the implementation activities of the department. These implementation activities are supplemented by detailed antidegradation review procedures developed under the state's continuing planning process. The department:

(1) obtains information pertinent to the impact of the effluent on the receiving water and advises the prospective discharger of requirements for obtaining a permit to discharge;

(2) reviews the adequacy of existing data and conducts a water quality survey of the receiving water in accordance with an annually reviewed, ranked priority list of surface waters of the state requiring total maximum daily loads pursuant to Section 303(d) of the federal Clean Water Act;

(3) assesses the probable impact of the effluent on the receiving water relative to its attainable or designated uses and numeric and narrative criteria;

(4) requires the highest and best degree of wastewater treatment practicable and commensurate with protecting and maintaining the designated uses and existing water quality of surface waters of the state;

(5) develops water quality based effluent limitations and comments on technology based effluent limitations, as appropriate, for inclusion in any federal permit issued to a discharger pursuant to Section 402 of the federal Clean Water Act;

(6) requires that these effluent limitations be included in any such permit as a condition for state certification pursuant to Section 401 of the federal Clean Water Act;

(7) coordinates its water pollution control activities with other constituent agencies of the commission, and with local, state and federal agencies, as appropriate;

(8) develops and pursues inspection and enforcement programs to ensure that dischargers comply with state regulations and standards, and complements EPA's enforcement of federal permits;

(9) ensures that the provisions for public participation required by the New Mexico Water Quality Act and the federal Clean Water Act are followed;

(10) provides continuing technical training for wastewater treatment facility operators through the utility operators training and certification programs;

(11) provides funds to assist the construction of publicly owned wastewater treatment facilities through the wastewater construction program authorized by Section 601 of the federal Clean Water Act, and through funds appropriated by the New Mexico legislature;

(12) conducts water quality surveillance of the surface waters of the state to assess the effectiveness of water pollution controls, determines whether water quality standards are being attained, and proposes amendments to improve water quality standards;

(13) encourages, in conjunction with other state agencies, implementation of the best management practices set forth in the New Mexico statewide water quality management plan and the nonpoint source management program, such implementation shall not be mandatory except as provided by federal or state law;

(14) evaluates the effectiveness of BMPs selected to prevent, reduce or abate sources of water pollutants;

(15) develops procedures for assessing use attainment as required by 20.6.4.15 NMAC and establishing site-specific standards; and

(16) develops list of surface waters of the state not attaining designated uses, pursuant to Sections 305(b) and 303(d) of the federal Clean Water Act.

[20.6.4.8 NMAC - Rp 20 NMAC 6.1.1101, 10/12/2000; A, 5/23/2005; A, 8/1/2007; A, 1/14/2011; A, 4/23/2022]

20.6.4.9 OUTSTANDING NATIONAL RESOURCE WATERS:

A. Procedures for nominating an ONRW: Any person may nominate a surface water of the state for designation as an ONRW by filing a petition with the commission pursuant to 20.1.6 NMAC, Rulemaking Procedures - Water Quality Control Commission. A petition to designate a surface water of the state as an ONRW shall include:

(1) a map of the surface water of the state, including the location and proposed upstream and downstream boundaries;

(2) a written statement and evidence based on scientific principles in support of the nomination, including specific reference to one or more of the applicable ONRW criteria listed in Subsection B of this section;

(3) water quality data including chemical, physical or biological parameters, if available, to establish a baseline condition for the proposed ONRW;

(4) a discussion of activities that might contribute to the reduction of water quality in the proposed ONRW;

(5) any additional evidence to substantiate such a designation, including a discussion of the economic impact of the designation on the local and regional economy within the state of New Mexico and the benefit to the state; and

(6) affidavit of publication of notice of the petition in a newspaper of general circulation in the affected counties and in a newspaper of general statewide circulation.

B. Criteria for ONRWs: A surface water of the state, or a portion of a surface water of the state, may be designated as an ONRW where the commission determines that the designation is beneficial to the state of New Mexico, and:

(1) the water is a significant attribute of a state special trout water, national or state park, national or state monument, national or state wildlife refuge or designated wilderness area, or is part of a designated wild river under the federal Wild and Scenic Rivers Act; or

(2) the water has exceptional recreational or ecological significance; or

(3) the existing water quality is equal to or better than the numeric criteria for protection of aquatic life and contact uses and the human health-organism only criteria, and the water has not been significantly modified by human activities in a manner that substantially detracts from its value as a natural resource.

C. Pursuant to a petition filed under Subsection A of this section, the commission may classify a surface water of the state or a portion of a surface water of the state as an ONRW if the criteria set out in Subsection B of this section are met.

D. Waters classified as ONRWs: The following waters are classified as ONRWs:

(1) Rio Santa Barbara, including the west, middle and east forks from their headwaters downstream to the boundary of the Pecos Wilderness; and

(2) the waters within the United States forest service Valle Vidal special management unit including:

(a) Rio Costilla, including Comanche, La Cueva, Fernandez, Chuckwagon, Little Costilla, Powderhouse, Holman, Gold, Grassy, LaBelle and Vidal creeks, from their headwaters downstream to the boundary of the United States forest service Valle Vidal special management unit;

(b) Middle Ponil creek, including the waters of Greenwood Canyon, from their headwaters downstream to the boundary of the Elliott S. Barker wildlife management area;

(c) Shuree lakes;

(d) North Ponil creek, including McCrystal and Seally Canyon creeks, from their headwaters downstream to the boundary of the United States forest service Valle Vidal special management unit; and

(e) Leandro creek from its headwaters downstream to the boundary of the United States forest service Valle Vidal special management unit.

(3) the named perennial surface waters of the state, identified in Subparagraph (a) below, located within United States department of agriculture forest service wilderness. Wilderness are those lands designated by the United States congress as wilderness pursuant to the Wilderness Act. Wilderness areas included in this designation are the Aldo Leopold wilderness, Apache Kid wilderness, Blue Range wilderness, Chama River Canyon wilderness, Cruces Basin wilderness, Dome wilderness, Gila wilderness, Latir Peak wilderness, Pecos wilderness, San Pedro Parks wilderness, Wheeler Peak wilderness, and White Mountain wilderness.

(a) The following waters are designated in the Rio Grande basin:

(i) in the Aldo Leopold wilderness: Byers Run, Circle Seven creek, Flower canyon, Holden Prong, Indian canyon, Las Animas creek, Mud Spring canyon, North Fork Palomas creek, North Seco creek, Pretty canyon, Sids Prong, South Animas canyon, Victorio Park canyon, Water canyon;

(ii) in the Apache Kid wilderness Indian creek and Smith canyon;

(iii) in the Chama River Canyon wilderness: Chavez canyon, Ojitos canyon, Rio Chama;

(iv) in the Cruces Basin wilderness: Beaver creek, Cruces creek, Diablo creek, Escondido creek, Lobo creek, Osha creek;

(v) in the Dome wilderness: Capulin creek, Medio creek, Sanchez canyon/creek;

(vi) in the Latir Peak wilderness: Bull creek, Bull Creek lake, Heart lake, Lagunitas Fork, Lake Fork creek, Rito del Medio, Rito Primero, West Latir creek;

(vii) in the Pecos wilderness: Agua Sarca, Hidden lake, Horseshoe lake (Alamitos), Jose Vigil lake, Nambe lake, Nat lake IV, No Fish lake, North Fork Rio Quemado, Rinconada, Rio Capulin, Rio de las Trampas (Trampas creek), Rio de Truchas, Rio Frijoles, Rio Medio, Rio Molino, Rio Nambe, Rio San Leonardo, Rito con Agua, Rito Gallina, Rito Jaroso, Rito Quemado, San Leonardo lake, Santa Fe lake, Santa Fe river, Serpent lake, South Fork Rio Quemado, Trampas lake (East), Trampas lake (West);

(viii) in the San Pedro Parks wilderness: Agua Sarca, Cañon Madera, Cave creek, Cecilia Canyon creek, Clear creek (North SPP), Clear creek (South SPP), Corralitos creek, Dove creek, Jose Miguel creek, La Jara creek, Oso creek, Rio Capulin, Rio de las Vacas, Rio Gallina, Rio Puerco de Chama, Rito Anastacio East, Rito Anastacio West, Rito de las Palomas, Rito de las Perchas, Rito de los Pinos, Rito de los Utes, Rito Leche, Rito Redondo, Rito Resumidero, San Gregorio lake;

(ix) in the Wheeler Peak wilderness: Black Copper canyon, East Fork Red river, Elk lake, Horseshoe lake, Lost lake, Sawmill creek, South Fork lake, South Fork Rio Hondo, Williams lake.

(b) The following waters are designated in the Pecos River basin:

(i) in the Pecos wilderness: Albright creek, Bear creek, Beatty creek, Beaver creek, Carpenter creek, Cascade canyon, Cave creek, El Porvenir creek, Hollinger creek, Holy Ghost creek, Horsethief creek, Jack's creek, Jarosa canyon/creek, Johnson lake, Lake Katherine, Lost Bear lake, Noisy brook, Panchuela creek, Pecos Baldy lake, Pecos river, Rio Mora, Rio Valdez, Rito Azul, Rito de los Chimayosos, Rito de los Esteros, Rito del Oso, Rito del Padre, Rito las Trampas, Rito Maestas, Rito Oscuro, Rito Perro, Rito Sebadilloses, South Fork Bear creek, South Fork Rito Azul, Spirit lake, Stewart lake, Truchas lake (North), Truchas lake (South), Winsor creek;

(ii) in the White Mountain wilderness: Argentina creek, Aspen creek, Bonito creek, Little Bonito creek, Mills canyon/creek, Rodamaker creek, South Fork Rio Bonito, Turkey canyon/creek.

(c) The following waters are designated in the Gila River basin:

(i) in the Aldo Leopold wilderness: Aspen canyon, Black Canyon creek, Bonner canyon, Burnt canyon, Diamond creek, Falls canyon, Fisherman canyon, Running Water canyon, South Diamond creek;

(ii) in the Gila wilderness: Apache creek, Black Canyon creek, Brush canyon, Canyon creek, Chicken Coop canyon, Clear creek, Cooper canyon, Cow creek, Cub creek, Diamond creek, East Fork Gila river, Gila river, Gilita creek, Indian creek, Iron creek, Langstroth canyon, Lilley canyon, Little creek, Little Turkey creek, Lookout canyon, McKenna creek, Middle Fork Gila river, Miller Spring canyon, Mogollon creek, Panther canyon, Prior creek, Rain creek, Raw Meat creek, Rocky canyon, Sacaton creek, Sapillo creek, Sheep Corral canyon, Skeleton canyon, Squaw creek, Sycamore canyon, Trail canyon, Trail creek, Trout creek, Turkey creek, Turkey Feather creek, Turnbo canyon, West Fork Gila river, West Fork Mogollon creek, White creek, Willow creek, Woodrow canyon.

(d) The following waters are designated in the Canadian River basin: in the Pecos wilderness Daily creek, Johns canyon, Middle Fork Lake of Rio de la Casa, Middle Fork Rio de la Casa, North Fork Lake of Rio de la Casa, Rito de Gascon, Rito San Jose, Sapello river, South Fork Rio de la Casa, Sparks creek (Manuelitas creek).

(e) The following waters are designated in the San Francisco River basin:

(i) in the Blue Range wilderness: Pueblo creek;

(ii) in the Gila wilderness: Big Dry creek, Lipsey canyon, Little Dry creek, Little Whitewater creek, South Fork Whitewater creek, Spider creek, Spruce creek, Whitewater creek.

(f) The following waters are designated in the Mimbres Closed basin: in the Aldo Leopold wilderness Corral canyon, Mimbres river, North Fork Mimbres river, South Fork Mimbres river.

(g) The following waters are designated in the Tularosa Closed basin: in the White Mountain wilderness Indian creek, Nogal Arroyo, Three Rivers.

(h) The wetlands designated are identified on the *Maps and List of Wetlands Within United States Forest Service Wilderness Areas Designated as Outstanding National Resource Waters* published at the New Mexico state library and available on the department's website.

(4) The following waters are designated in the headwaters Pecos river watershed:

(a) The Pecos river from Dalton Canyon creek to the Pecos wilderness boundary;

(b) In the Dry Gulch-Pecos river subwatershed, Dalton Canyon creek from the Pecos river upstream to the headwaters, Wild Horse creek from Dalton Canyon creek upstream to the headwaters, Macho Canyon creek from the Pecos river upstream to the headwaters and Sawyer creek from the Pecos river upstream to the headwaters;

(c) In the Indian creek-Pecos river subwatershed, Indian creek from the Pecos river upstream to the headwaters, Holy Ghost creek from the Pecos river upstream to the Pecos wilderness boundary, Doctor creek from Holy Ghost creek upstream to the headwaters, Davis creek from the Pecos river upstream to the headwaters and Willow creek from the Pecos river upstream to the headwaters;

(d) In the Rio Mora subwatershed, Rio Mora from the Pecos river upstream to the Pecos wilderness boundary and Bear creek from the Rio Mora upstream to the Pecos wilderness boundary;

(e) In the Rio Mora-Pecos river subwatershed, Carpenter creek from the Pecos river upstream to the Pecos wilderness boundary, Winsor creek from the Pecos river upstream to the Pecos wilderness boundary and Jack's creek from the Pecos river upstream to the Pecos wilderness boundary; and,

(f) In the Panchuela creek subwatershed, Panchuela creek from the Pecos river upstream to the Pecos wilderness boundary;

(g) Unnamed tributaries to waters in Subparagraphs (a) through (f), Paragraph (4) of this Subsection (D) as identified in the *Maps and Lists for Unnamed Tributaries to Perennial Waters and Wetlands in the Headwaters Pecos River Watershed*, published at the New Mexico state library and available on the department's website.

(h) Unnamed wetlands adjacent to waters in Subparagraphs (a) through (f), Paragraph (4) of this Subsection (D) as identified in the *Maps and Lists for Unnamed Tributaries to Perennial Waters and Wetlands in the Headwaters Pecos River Watershed*, published at the New Mexico state library and available on the department's website.

(5) the Rio Grande from directly above the Rio Pueblo de Taos to the New Mexico-Colorado state border.

(6) the Rio Hondo from the Carson National Forest boundary to its headwaters; and Lake Fork creek from the Rio Hondo to its headwaters.

(7) the East Fork Jemez river from San Antonio creek to its headwaters; San Antonio creek from the East Fork Jemez river to its headwaters; and Redondo creek from Sulphur creek to its headwaters.

[20.6.4.9 NMAC - Rn, Subsections B, C and D of 20.6.4.8 NMAC, 5/23/2005; A, 5/23/2005; A, 7/17/2005; A, 2/16/2006; A, 12/1/2010; A, 1/14/2011; A, 4/23/2022; A, 09/24/2022]

20.6.4.10 REVIEW OF STANDARDS; NEED FOR ADDITIONAL STUDIES:

A. Section 303(c)(1) of the federal Clean Water Act requires that the state hold public hearings at least once every three years for the purpose of reviewing water quality standards and proposing, as appropriate, necessary revisions to water quality standards.

B. In accordance with 40 CFR 131.10(i), when an existing use, as defined under 20.6.4.7 NMAC, is higher quality water than prescribed by the designated use and supporting evidence demonstrates the presence of that use, the designated use shall be amended accordingly to have criteria no less stringent than the existing use.

C. It is recognized that, in some cases, numeric criteria for a particular designated use may not adequately reflect the local conditions or the aquatic communities adapted to those localized conditions. In these cases, a water quality criterion may be modified to reflect the natural condition of a specific waterbody. The modification of the criterion does not change the designated use; the modification only changes the criterion for that specific waterbody When justified by sufficient data and information, a numeric water quality criterion may be adopted or modified in accordance with Subsection F of 20.6.4.10 and Subsection G of 20.6.4.10 NMAC, to protect the attainable uses of the waterbody.

D. The removal or amendment of a designated use to a designated use with less stringent criteria can only be done through a use attainability analysis in accordance with 20.6.4.15 NMAC.

E. It is also recognized that contributions of water contaminants by diffuse nonpoint sources of water pollution may make attainment of certain criteria difficult. Revision of these criteria may be necessary as new information is obtained on nonpoint sources and other problems unique to semi-arid regions.

F. Site-specific criteria.

(1) The commission may adopt site-specific numeric criteria applicable to all or part of a surface water of the state based on relevant site-specific conditions such as:

(a) actual species at a site are more or less sensitive than those used in the national criteria data set;

(b) physical or chemical characteristics at a site such as pH or hardness alter the biological availability and/or toxicity of the chemical;

(c) physical, biological or chemical factors alter the bioaccumulation potential of a chemical;

(d) the concentration resulting from natural background exceeds numeric criteria for aquatic life, wildlife habitat or other uses if consistent with Subsection G of 20.6.4.10 NMAC; or

(e) other factors or combination of factors that upon review of the commission may warrant modification of the default criteria, subject to EPA review and approval.

(2) Site-specific criteria must fully protect the designated use to which they apply. In the case of human health-organism only criteria, site-specific criteria must fully protect human health when organisms are consumed from waters containing pollutants.

(3) Any person may petition the commission to adopt site-specific criteria. A petition for the adoption of site-specific criteria shall:

(a) identify the specific waters to which the site-specific criteria would apply;

(b) explain the rationale for proposing the site-specific criteria;

(c) describe the methods used to notify and solicit input from potential stakeholders and from the general public in the affected area, and present and respond to the public input received;

(d) present and justify the derivation of the proposed criteria.

(4) A derivation of site-specific criteria shall rely on a scientifically defensible method, such as one of the following:

(a) the recalculation procedure, the water-effect ratio for metals procedure or the resident species procedure as described in the water quality standards handbook (EPA-823-B-94-005a, 2nd edition, August 1994);

(b) the streamlined water-effect ratio procedure for discharges of copper (EPA-822-R-01-005, March 2001);

(c) the biotic ligand model as described in aquatic life ambient freshwater quality criteria - copper (EPA-822-R-07-001, February 2007);

(d) the methodology for deriving ambient water quality criteria for the protection of human health (EPA-822-B-00-004, October 2000) and associated technical support documents; or

(e) a determination of the natural background of the water body as described in Subsection G of 20.6.4.10 NMAC.

G. Site-specific criteria based on natural background. The commission may adopt site-specific criteria equal to the concentration resulting from natural background where that concentration protects the designated use. The concentration resulting from natural background supports the level of aquatic life and wildlife habitat expected to occur naturally at the site absent any interference by humans. Domestic water supply, primary or secondary contact, or human health-organism only criteria shall not be modified based on natural background. A determination of natural background shall:

(1) consider natural spatial and seasonal to interannual variability as appropriate;

(2) document the presence of natural sources of the pollutant;

(3) document the absence of human sources of the pollutant or quantify the human contribution; and

(4) rely on analytical, statistical or modeling methodologies to quantify the natural background.

H. Temporary standards.

(1) Any person may petition the commission to adopt a temporary standard applicable to all or part of a surface water of the state as provided for in this section and applicable sections in 40 CFR Part 131, Water Quality Standards; specifically, Section 131.14. The commission may adopt a proposed temporary standard if the petitioner demonstrates that:

(a) attainment of the associated designated use may not be feasible in the short term due to one or more of the factors listed in 40 CFR 131.10(g), or due to the implementation of actions necessary to facilitate restoration such as through dam removal or other significant wetland or water body reconfiguration activities as demonstrated by the petition and supporting work plan requirements in Paragraphs (4) and (5) of Subsection H of 20.6.4.10 NMAC;

(b) the proposed temporary standard represents the highest degree of protection feasible in the short term, limits the degradation of water quality to the minimum necessary to achieve the original standard by the expiration date of the temporary standard, and adoption will not cause the further impairment or loss of an existing use;

(c) for point sources, existing or proposed discharge control technologies will comply with applicable technology-based limitations and feasible technological controls and other management alternatives, such as a pollution prevention program; and

(d) for restoration activities, nonpoint source or other control technologies shall limit downstream impacts, and if applicable, existing or proposed discharge control technologies shall be in place consistent with Subparagraph (c) of Paragraph (1) of Subsection H of 20.6.4.10 NMAC.

(2) A temporary standard shall apply to specific designated use(s), pollutant(s), or permittee(s), and to specific water body segment(s). The adoption of a temporary standard does not exempt dischargers from complying with all other applicable water quality standards or control technologies.

(3) Designated use attainment as reported in the federal Clean Water Act, Section 305(b)/303(d) Integrated Report shall be based on the original standard and not on a temporary standard.

(4) A petition for a temporary standard shall:

(a) identify the currently applicable standard(s), the proposed temporary standard for the specific pollutant(s), the permittee(s), and the specific surface water body segment(s) of the state to which the temporary standard would apply;

(b) include the basis for any factor(s) specific to the applicability of the temporary standard (for example critical flow under Subsection B of 20.6.4.11 NMAC);

(c) demonstrate that the proposed temporary standard meets the requirements in this subsection;

(d) present a work plan with timetable of proposed actions for achieving compliance with the original standard in accordance with Paragraph (5) of Subsection H of 20.6.4.10 NMAC;

(e) include any other information necessary to support the petition.

(5) As a condition of a petition for a temporary standard, in addition to meeting the requirements in this Subsection, the petitioner shall prepare a work plan in accordance with Paragraph (4) of Subsection H of 20.6.4.10 NMAC and submit the work plan to the department for review and comment. The work plan shall identify the factor(s) listed in 40 CFR 131.10(g) or Subparagraph (a) of Paragraph (1) of Subsection H of 20.6.4.10 NMAC affecting attainment of the standard that will be analyzed and the timeline for proposed actions to be taken to achieve the uses attainable over the term of the temporary standard, including baseline water quality, and any investigations, projects, facility modifications, monitoring, or other measures necessary to achieve compliance with the original standard. The work plan shall include provisions for review of progress in accordance with Paragraph (8) of Subsection H of 20.6.4.10 NMAC, public notice and consultation with appropriate state, tribal, local and federal agencies.

(6) The commission may condition the approval of a temporary standard by requiring additional monitoring, relevant analyses, the completion of specified projects, submittal of information, or any other actions.

(7) Temporary standards may be implemented only after a public hearing before the commission, commission approval and adoption pursuant to Subsection H of 20.6.4.10 NMAC for all state purposes, and the federal Clean Water Act Section 303 (c) approval for any federal action.

(8) All temporary standards are subject to a required review during each succeeding review of water quality standards conducted in accordance with Subsection A of 20.6.4.10 NMAC. The petitioner shall provide a written report to the commission documenting the progress of proposed actions, pursuant to a reporting schedule stipulated in the approved temporary standard. The purpose of the review is to determine progress consistent with the original conditions of the petition for the duration of the temporary standard. If the petitioner cannot demonstrate that sufficient progress has been made the commission may revoke approval of the temporary standard or provide additional conditions to the approval of the temporary standard.

(9) The commission may consider a petition to extend a temporary standard. The effective period of a temporary standard shall be extended only if demonstrated to the commission that the factors precluding attainment of the underlying standard still apply, that the petitioner is meeting the conditions required for approval of the temporary standard, and that reasonable progress towards meeting the underlying standard is being achieved.

(10) A temporary standard shall expire no later than the date specified in the approval of the temporary standard. Upon expiration of a temporary standard, the original standard becomes applicable.

(11) Temporary standards shall be identified in 20.6.4.97-899 NMAC as appropriate for the surface water affected.

(12) "Temporary standard" means a time-limited designated use and criterion for a specific pollutant(s) or water quality parameter(s) that reflect the highest attainable condition during the term of the temporary standard.

[20.6.4.10 NMAC - Rp 20 NMAC 6.1.1102, 10/12/2000; Rn, 20.6.4.9 NMAC, 5/23/2005; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017; A, 4/23/2022]

20.6.4.11 APPLICABILITY OF WATER QUALITY STANDARDS:

A. [**RESERVED**]

B. Critical low flow: The critical low flow of a stream at a particular site shall be used in developing point source discharge permit requirements to meet numeric criteria set in 20.6.4.97 through 20.6.4.900 NMAC and Subsection F of 20.6.4.13 NMAC.

(1) For human health-organism only criteria, the critical low flow is the harmonic mean flow. For ephemeral waters the calculation shall be based upon the nonzero flow intervals and modified by including a factor to adjust for the proportion of intervals with zero flow. The equations are as follows:

$$\text{Harmonic Mean} = \frac{n}{\sum 1/Q}$$

where n = number of flow values

and Q = flow value

$$\text{Modified Harmonic Mean} = \left[\frac{\sum_{i=1}^{Nt-N_0} \frac{1}{Qi}}{Nt-N_0}\right]^{-1} x \left[\frac{Nt-N_0}{Nt}\right]$$

where Qi = nonzero flow

Nt = total number of flow values

and N_0 = number of zero flow values

(2) For all other narrative and numeric criteria, the critical low flow is the minimum average four consecutive day flow that occurs with a frequency of once in three years (4Q3). The critical low flow may be determined on an annual, a seasonal or a monthly basis, as appropriate, after due consideration of site-specific conditions.

C. Guaranteed minimum flow: The commission may allow the use of a contractually guaranteed minimum streamflow in lieu of a critical low flow determined under Subsection B of this section on a case-by-case basis and upon consultation with the interstate stream commission. Should drought, litigation or any other reason interrupt or interfere with minimum flows under a guaranteed minimum flow contract for a period of at least 30 consecutive days, such permission, at the sole discretion of the commission, may then be revoked. Any minimum flow specified under such revoked permission shall be superseded by a critical low flow determined under Subsection B of this section. A public notice of the request for a guaranteed minimum flow shall be published in a newspaper of general circulation by the department at least 30 days prior to scheduled action by the commission. These water quality standards do not grant to the commission or any other entity the power to create, take away or modify property rights in water.

D. **Mixing zones:** A limited mixing zone, contiguous to a point source wastewater discharge, may be allowed in any stream receiving such a discharge. Mixing zones serve as regions of initial dilution that allow the application of a dilution factor in calculations of effluent limitations. Effluent limitations shall be developed that will protect the most sensitive existing, designated or attainable use of the receiving water.

E. **Mixing zone limitations:** Wastewater mixing zones, in which the numeric criteria set under Subsection F of 20.6.4.13 NMAC, 20.6.4.97 through 20.6.4.899 NMAC or 20.6.4.900 NMAC may be exceeded, shall be subject to the following limitations:

(1) Mixing zones are not allowed for discharges to lakes, reservoirs, or playas; these effluents shall meet all applicable criteria set under Subsection F of 20.6.4.13 NMAC, 20.6.4.97 through 20.6.4.899 NMAC and 20.6.4.900 NMAC at the point of discharge.

(2) The acute aquatic life criteria, as set out in Subsection I, Subsection J, and Subsection K of 20.6.4.900 NMAC, shall be attained at the point of discharge for any discharge to a surface water of the state with a designated aquatic life use.

(3) The general criteria set out in Subsections A, B, C, D, E, G, H and J of 20.6.4.13 NMAC, and the provision set out in Subsection D of 20.6.4.14 NMAC are applicable within mixing zones.

(4) The areal extent and concentration isopleths of a particular mixing zone will depend on site-specific conditions including, but not limited to, wastewater flow, receiving water critical low flow, outfall design, channel characteristics and climatic conditions and, if needed, shall be determined on a case-by-case basis. When the physical boundaries or other characteristics of a particular mixing zone must be known, the methods presented in Section 4.4.5, “Ambient-induced mixing,” in “Technical support document for water quality-based toxics control” (March 1991, EPA/505/2-90-001) shall be used.

(5) All applicable water quality criteria set under Subsection F of 20.6.4.13 NMAC, 20.6.4.97 through 20.6.4.899 NMAC and 20.6.4.900 NMAC shall be attained at the boundaries of mixing zones. A continuous zone of passage through or around the mixing zone shall be maintained in which the water quality meets all applicable criteria and allows the migration of aquatic life presently common in surface waters of the state with no effect on their populations.

F. **Multiple uses:** When a surface water of the state has more than a single designated use, the applicable numeric criteria shall be the most stringent of those established for such water.

G. Human health-organism only criteria in Subsection J of 20.6.4.900 NMAC apply to those waters with a designated, existing or attainable aquatic life use. When limited aquatic life is a designated use, the human health-organism only criteria apply only if adopted on a segment-specific basis. The human health-organism only criteria for persistent toxic pollutants, as identified in Subsection J of 20.6.4.900 NMAC, also apply to all tributaries of waters with a designated, existing or attainable aquatic life use.

H. **Unclassified waters of the state:** An unclassified surface water of the state is presumed to support the uses specified in Section 101(a)(2) of the federal Clean Water Act. As such, it is subject to 20.6.4.98 NMAC if nonperennial or subject to 20.6.4.99 NMAC if perennial. The commission may include an ephemeral unclassified surface water of the state under 20.6.4.97 NMAC only if a use attainability analysis demonstrates pursuant to 20.6.4.15 NMAC that attainment of Section 101(a)(2) uses is not feasible.

I. **Exceptions:** Numeric criteria for temperature, dissolved solids, dissolved oxygen, sediment or turbidity adopted under the Water Quality Act do not apply when changes in temperature, dissolved solids, dissolved oxygen, sediment or turbidity in a surface water of the state are attributable to:

(1) natural causes (discharges from municipal separate storm sewers are not covered by this exception.); or

(2) the reasonable operation of irrigation and flood control facilities that are not subject to federal or state water pollution control permitting; major reconstruction of storage dams or diversion dams except for emergency actions necessary to protect health and safety of the public are not covered by this exception.

[20.6.4.11 NMAC - Rp 20 NMAC 6.1.1103, 10/12/2000; A, 10/11/2002; Rn, 20.6.4.10 NMAC, 5/23/2005; A, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

20.6.4.12 **COMPLIANCE WITH WATER QUALITY STANDARDS:** The following provisions apply to determining compliance for enforcement purposes; they do not apply for purposes of determining attainment of uses. The department has developed assessment protocols for the purpose of determining attainment of uses that are available for review from the department's surface water quality bureau.

A. Compliance with acute water quality criteria shall be determined from the analytical results of a single grab sample. Acute criteria shall not be exceeded.

B. Compliance with chronic water quality criteria shall be determined from the arithmetic mean of the analytical results of samples collected using applicable protocols. Chronic criteria shall not be exceeded more than once every three years.

C. Compliance with water quality standards for total ammonia shall be determined by performing the biomonitoring procedures set out in Subsections D and E of 20.6.4.14 NMAC, or by attainment of applicable ammonia criteria set out in Subsections K, L and M of 20.6.4.900 NMAC.

D. Compliance with the human health-organism only criteria shall be determined from the analytical results of representative grab samples, as defined in the water quality management plan. Human health-organism only criteria shall not be exceeded.

E. The commission may establish a numeric water quality criterion at a concentration that is below the minimum quantification level. In such cases, the water quality standard is enforceable at the minimum quantification level.

F. For compliance with hardness-dependent numeric criteria, hardness (as mg $CaCO_3$/L) shall be determined from a sample taken at the same time that the sample for the contaminant is taken.

G. **Compliance schedules:** The commission may allow the inclusion of a schedule of compliance in a NPDES permit issued to an existing facility on a case-by-case basis. Such schedule of compliance will be for the purpose of providing a permittee with adequate time to make treatment facility modifications necessary to comply with water quality based permit limitations determined to be necessary to implement new or revised water quality standards or wasteload allocation. Compliance schedules may be included in NPDES permits at the time of permit renewal or modification and shall be written to require compliance at the earliest practicable time. Compliance schedules shall also specify milestone dates so as to measure progress towards final project completion (e.g., design completion, construction start, construction completion, date of compliance).

H. It is a policy of the commission to allow a temporary standard approved and adopted pursuant to Subsection H of 20.6.4.10 NMAC to be included in the applicable federal Clean Water Act permit as enforceable limits and conditions. The temporary standard and any schedule of actions may be included at the earliest practicable time, and shall specify milestone dates so as to measure progress towards meeting the original standard.
[20.6.4.12 NMAC - Rp 20 NMAC 6.1.1104, 10/12/2000; A, 10/11/2002; Rn, 20.6.4.11 NMAC, 5/23/2005; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017; A, 4/23/2022]

20.6.4.13 GENERAL CRITERIA: General criteria are established to sustain and protect existing or attainable uses of surface waters of the state. These general criteria apply to all surface waters of the state at all times, unless a specified criterion is provided elsewhere in this part. Surface waters of the state shall be free of any water contaminant in such quantity and of such duration as may with reasonable probability injure human health, animal or plant life or property, or unreasonably interfere with the public welfare or the use of property.

A. **Bottom deposits and suspended or settleable solids:**

(1) Surface waters of the state shall be free of water contaminants including fine sediment particles (less than two millimeters in diameter), precipitates or organic or inorganic solids from other than natural causes that have settled to form layers on or fill the interstices of the natural or dominant substrate in quantities that damage or impair the normal growth, function or reproduction of aquatic life or significantly alter the physical or chemical properties of the bottom.

(2) Suspended or settleable solids from other than natural causes shall not be present in surface waters of the state in quantities that damage or impair the normal growth, function or reproduction of aquatic life or adversely affect other designated uses.

B. **Floating solids, oil and grease:** Surface waters of the state shall be free of oils, scum, grease and other floating materials resulting from other than natural causes that would cause the formation of a visible sheen or visible deposits on the bottom or shoreline, or would damage or impair the normal growth, function or reproduction of human, animal, plant or aquatic life.

C. **Color:** Color-producing materials resulting from other than natural causes shall not create an aesthetically undesirable condition nor shall color impair the use of the water by desirable aquatic life presently common in surface waters of the state.

D. **Organoleptic quality:**

(1) Flavor of fish: Water contaminants from other than natural causes shall be limited to concentrations that will not impart unpalatable flavor to fish.

(2) Odor and taste of water: Water contaminants from other than natural causes shall be limited to concentrations that will not result in offensive odor or taste arising in a surface water of the state or otherwise interfere with the reasonable use of the water.

E. Plant nutrients: Plant nutrients from other than natural causes shall not be present in concentrations that will produce undesirable aquatic life or result in a dominance of nuisance species in surface waters of the state.

F. Toxic pollutants:

(1) Except as provided in 20.6.4.16 NMAC, surface waters of the state shall be free of toxic pollutants from other than natural causes in amounts, duration, concentrations, or combinations that affect the propagation of fish or that are toxic to humans, livestock or other animals, fish or other aquatic organisms, wildlife using aquatic environments for habitation or aquatic organisms for food, or that will or can reasonably be expected to bioaccumulate in tissues of fish, shellfish and other aquatic organisms to levels that will impair the health of aquatic organisms or wildlife or result in unacceptable tastes, odors or health risks to human consumers of aquatic organisms.

(2) Pursuant to this section, the human health-organism only criteria shall be as set out in 20.6.4.900 NMAC. When a human health-organism only criterion is not listed in 20.6.4.900 NMAC, the following provisions shall be applied in accordance with 20.6.4.11, 20.6.4.12 and 20.6.4.14 NMAC.

(a) The human health-organism only criterion shall be the recommended human health criterion for "consumption of organisms only" published by the U.S. environmental protection agency pursuant to Section 304(a) of the federal Clean Water Act. In determining such criterion for a cancer-causing toxic pollutant, a cancer risk of 10^{-5} (one cancer per 100,000 exposed persons) shall be used.

(b) When a numeric criterion for the protection of human health for the consumption of organism only has not been published by the U.S. environmental protection agency, a quantifiable criterion may be derived from data available in the U.S. environmental protection agency's Integrated Risk Information System (IRIS) using the appropriate formula specified in *Methodology for Deriving Ambient Water Quality Criteria for The Protection Of Human Health (2000)*, EPA-822-B-00-004.

(3) Pursuant to this section, the chronic aquatic life criteria shall be as set out in 20.6.4.900 NMAC. When a chronic aquatic life criterion is not listed in 20.6.4.900 NMAC, the following provisions shall be applied in sequential order in accordance with 20.6.4.11, 20.6.4.12 and 20.6.4.14 NMAC.

(a) The chronic aquatic life criterion shall be the "freshwater criterion continuous concentration" published by the U.S. environmental protection agency pursuant to Section 304(a) of the federal Clean Water Act;

(b) If the U.S. environmental protection agency has not published a chronic aquatic life criterion, a geometric mean LC-50 value shall be calculated for the particular species, genus or group that is representative of the form of life to be preserved, using the results of toxicological studies published in scientific journals.

(i) The chronic aquatic life criterion for a toxic pollutant that does not bioaccumulate shall be ten percent of the calculated geometric mean LC-50 value; and

(ii) The chronic aquatic life criterion for a toxic pollutant that does bioaccumulate shall be: the calculated geometric mean LC-50 adjusted by a bioaccumulation factor for the particular species, genus or group representative of the form of life to be preserved, but when such bioaccumulation factor has not been published, the criterion shall be one percent of the calculated geometric mean LC-50 value.

(4) Pursuant to this section, the acute aquatic life criteria shall be as set out in 20.6.4.900 NMAC. When an acute aquatic life criterion is not listed in 20.6.4.900 NMAC, the acute aquatic life criterion shall be the "freshwater criterion maximum concentration" published by the U.S. environmental protection agency pursuant to Section 304(a) of the federal Clean Water Act.

(5) Within 90 days of the issuance of a final NPDES permit containing a numeric criterion selected or calculated pursuant to Paragraph (2), Paragraph (3) or Paragraph (4) of Subsection F of this section, the department shall petition the commission to adopt such criterion into these standards.

G. Radioactivity: The radioactivity of surface waters of the state shall be maintained at the lowest practical level and shall in no case exceed the criteria set forth in the New Mexico Radiation Protection Regulations, 20.3.1 and 20.3.4 NMAC.

H. Pathogens: Surface waters of the state shall be free of pathogens from other than natural causes in sufficient quantity to impair public health or the designated, existing or attainable uses of a surface water of the state.

I. Temperature: Maximum temperatures for surface waters of the state have been specified in 20.6.4.97 through 20.6.4.900 NMAC. However, the introduction of heat by other than natural causes shall not increase the temperature, as measured from above the point of introduction, by more than 2.7°C (5°F) in a stream, or more than 1.7°C (3°F) in a lake or reservoir. In no case will the introduction of heat be permitted when the maximum temperature specified for the reach would thereby be exceeded. These temperature criteria shall not apply to impoundments constructed offstream for the purpose of heat disposal. High water temperatures caused by unusually high ambient air temperatures are not violations of these criteria.

J. Turbidity: Turbidity attributable to other than natural causes shall not reduce light transmission to the point that the normal growth, function or reproduction of aquatic life is impaired or that will cause substantial visible contrast with the natural appearance of the water. Activities or discharges shall not cause turbidity to increase more than 10 NTU over background turbidity when the background turbidity, measured at a point immediately upstream of the activity, is 50 NTU or less, nor to increase more than twenty percent when the background turbidity is more than 50 NTU. However, limited-duration turbidity increases caused by dredging, construction or other similar activities may be allowed provided all practicable turbidity control techniques have been applied and all appropriate permits, certifications and approvals have been obtained.

K. Total dissolved solids (TDS): TDS attributable to other than natural causes shall not damage or impair the normal growth, function or reproduction of animal, plant or aquatic life. TDS shall be measured by either the "calculation method" (sum of constituents) or the filterable residue method. Approved test procedures for these determinations are set forth in 20.6.4.14 NMAC.

L. Dissolved gases: Surface waters of the state shall be free of nitrogen and other dissolved gases at levels above one hundred ten percent saturation when this supersaturation is attributable to municipal, industrial or other discharges.

M. Biological integrity: Surface waters of the state shall support and maintain a balanced and integrated community of aquatic organisms with species composition, diversity and functional organization comparable to those of natural or minimally impacted water bodies of a similar type and region.
[20.6.4.13 NMAC - Rp 20 NMAC 6.1.1105, 10/12/2000; A, 10/11/2002; Rn, 20.6.4.12 NMAC, 5/23/2005; A, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

20.6.4.14 SAMPLING AND ANALYSIS:

A. Sampling and analytical techniques shall conform with methods described in the following references unless otherwise specified by the commission pursuant to a petition to amend these standards:

(1) "*Guidelines Establishing Test Procedures For The Analysis Of Pollutants Under The Clean Water Act*," 40 CFR Part 136 or any test procedure approved or accepted by EPA using procedures provided in 40 CFR Parts 136.3(d), 136.4, and 136.5;

(2) *Standard Methods For The Examination Of Water And Wastewater*, latest edition, American public health association;

(3) *Methods For Chemical Analysis Of Water And Waste*, and other methods published by EPA office of research and development or office of water;

(4) *Techniques Of Water Resource Investigations Of The U.S. Geological Survey*;

(5) *Annual Book Of ASTM Standards*: volumes 11.01 and 11.02, water (I) and (II), latest edition, ASTM international;

(6) *Federal Register*, latest methods published for monitoring pursuant to Resource Conservation and Recovery Act regulations;

(7) *National Handbook Of Recommended Methods For Water-Data Acquisition*, latest edition, prepared cooperatively by agencies of the United States government under the sponsorship of the U.S. geological survey; or

(8) *Federal Register*, latest methods published for monitoring pursuant to the Safe Drinking Water Act regulations.

B. Bacteriological Surveys: The monthly geometric mean shall be used in assessing attainment of criteria when a minimum of five samples is collected in a 30-day period.

C. Sampling Procedures:

(1) Streams: Stream monitoring stations below discharges shall be located a sufficient distance downstream to ensure adequate vertical and lateral mixing.

(2) Lakes: Sampling stations in lakes shall be located at least 250 feet from a discharge.

(3) Lakes: Except for the restriction specified in Paragraph (2) of this subsection, lake sampling stations shall be located at any site where the attainment of a water quality criterion is to be assessed. Water quality measurements taken at intervals in the entire water column at a sampling station shall be averaged for the epilimnion, or in the absence of an epilimnion, for the upper one-third of the water column of the lake to determine attainment of criteria, except that attainment of criteria for toxic pollutants shall be assessed during periods of complete vertical mixing, e.g., during spring or fall turnover, or by taking depth-integrated composite samples of the water column.

D. Acute toxicity of effluent to aquatic life shall be determined using the procedures specified in U.S. environmental protection agency "*Methods for Measuring The Acute Toxicity of Effluents and Receiving Waters To Freshwater and Marine Organisms*" (5th Ed., 2002, EPA 821-R-02-012), or latest edition thereof if adopted by EPA at 40 CFR Part 136, which is incorporated herein by reference. Acute toxicities of substances shall be determined using at least two species tested in whole effluent and a series of effluent dilutions. Acute toxicity due to discharges shall not occur within the wastewater mixing zone in any surface water of the state with an existing or designated aquatic life use.

E. Chronic toxicity of effluent or ambient surface waters of the state to aquatic life shall be determined using the procedures specified in U.S. environmental protection agency "*Short-Term Methods For Estimating The Chronic Toxicity Of Effluents And Receiving Waters To Freshwater Organisms*" (4th Ed., 2002, EPA 821-R-02-013), or latest edition thereof if adopted by EPA at 40 CFR Part 136, which is incorporated herein by reference. Chronic toxicities of substances shall be determined using at least two species tested in ambient surface water or whole effluent and a series of effluent dilutions. Chronic toxicity due to discharges shall not occur at the critical low flow, or any flow greater than the critical low flow, in any surface water of the state with an existing or designated aquatic life use more than once every three years.

F. Emerging Contaminants Monitoring: The department may require monitoring, analysis and reporting of emerging contaminants as a condition of a federal permit under Section 401 of the federal Clean Water Act.

[20.6.4.14 NMAC - Rp 20 NMAC 6.1.1106, 10/12/2000; Rn, 20.6.4.13 NMAC, 5/23/2005 & A, 5/23/2005; A, 12/1/2010; A 4/23/2022]

20.6.4.15 USE ATTAINABILITY ANALYSIS:

A. Regulatory requirements for a use attainability analysis. Whenever a use attainability analysis is conducted, it shall be subject to the requirements and limitations set forth in 40 CFR Part 131, Water Quality Standards; specifically, Subsections 131.3(g), 131.10(g), 131.10(h) and 131.10(j) shall be applicable. In accordance with 40 CFR 131.10(i), and 20.6.4.10 NMAC, the amendment of a designated use, based on an existing use with more stringent criteria, does not require a use attainability analysis.

(1) The commission may remove a designated use, that is not an existing use, specified in Section 101(a)(2) of the federal Clean Water Act or adopt subcategories of a use in Section 101(a)(2) of the federal Clean Water Act requiring less stringent criteria only if a use attainability analysis demonstrates that attaining the use is not feasible because of a factor listed in 40 CFR 131.10(g). Uses in Section 101(a)(2) of the federal Clean Water Act, which refer to the protection and propagation of fish, shellfish and wildlife and recreation in and on the water, are also specified in Subsection B of 20.6.4.6 NMAC.

(2) A designated use cannot be removed if it is an existing use unless a use requiring more stringent criteria is designated.

B. Methods for developing a use attainability analysis. A use attainability analysis shall assess the physical, chemical, biological, economic or other factors affecting the attainment of a use. The analysis shall rely on scientifically defensible methods such as the methods described in the following documents:

(1) *Technical Support Manual: Waterbody Surveys And Assessments For Conducting Use Attainability Analyses*, volume I (November 1983) and volume III (November 1984) or latest editions, United States environmental protection agency, office of water, regulations and standards, Washington, D.C., for the evaluation of aquatic life or wildlife uses;

(2) the department's *Hydrology Protocol*, latest edition, approved by the commission, for identifying ephemeral, intermittent, and perennial waters; or

(3) *Interim Economic Guidance For Water Quality Standards - Workbook*, March 1995, United States environmental protection agency, office of water, Washington, D.C. for evaluating economic impacts.

C. Determining the highest attainable use. If the use attainability analysis determines that the designated use is not attainable based on one of the factors in 40 CFR 131.10(g), the use attainability analysis shall demonstrate the support for removing the designated use and then determine the highest attainable use, as defined in 40 CFR 131.3(m), for the protection and propagation of fish, shellfish and wildlife and recreation in and on the water based on methods described in Subsection B of this section.

D. Process to amend a designated use through a use attainability analysis.

(1) The process for developing a use attainability analysis and petitioning the commission for removing a designated use and establishing the highest attainable use shall be done in accordance with the State's current *Water Quality Management Plan/Continuing Planning Process*.

(2) If the findings of a use attainability analysis, conducted by the department, in accordance with the department's *Hydrology Protocol* (latest edition) demonstrates that federal Clean Water Act Section 101(a)(2) uses, that are not existing uses, are not feasible in an ephemeral water body due to the factor in 40 CFR 131.10(g)(2), the department may consider proceeding with the expedited use attainability analysis process in accordance with the State's current *Water Quality Management Plan/Continuing Planning Process*. The following elements must be met for the expedited use attainability analysis process to be authorized and implemented:

(a) The department is the primary investigator of the use attainability analysis;

(b) The use attainability analysis determined, through the application of the *Hydrology Protocol*, that the water being investigated is ephemeral and has no effluent discharges of sufficient volume that could compensate for the low-flow;

(c) The use attainability analysis determined that the criteria associated with the existing uses of the water being investigated are not more stringent than those in 20.6.4.97 NMAC;

(d) The designated uses in 20.6.4.97 NMAC have been determined to be the highest attainable uses for the water being analyzed;

(e) The department posted the use attainability analysis on its water quality standards website and notified its interested parties list of a 30-day public comment period;

(f) The department reviewed and responded to any comments received during the 30-day public comment period ; and

(g) The department submitted the use attainability analysis and response to comments to region 6 EPA for technical approval.

If EPA approves the revision under section 303(c) of the Clean Water Act, the water shall be subject to 20.6.4.97 NMAC for federal Clean Water Act purposes. The use attainability analysis, the technical support document, and the applicability of 20.6.4.97 NMAC to the water shall be posted on the department's water quality standards website. The department shall periodically petition the commission to list ephemeral waters under Subsection C of 20.6.4.97 NMAC and to incorporate changes to classified segments as appropriate.

E. Use attainability analysis conducted by an entity other than the department. Any person may submit notice to the department stating their intent to conduct a use attainability analysis.

(1) The proponent shall provide such notice along with a work plan supporting the development of a use attainability analysis to the department and region 6 EPA for review and comment.

(2) Upon approval of the work plan by the department, the proponent shall conduct the use attainability analysis in accordance with the applicable portions of Subsections A through D of this Section and implement public noticing in accordance with the approved work plan.

(3) Work plan elements. The work plan shall identify, at a minimum:

(a) the waterbody of concern and the reasoning for conducting a use attainability analysis;

(b) the source and validity of data to be used to demonstrate whether the current designated use is not attainable;

(c) the factors in 40 CFR 131.10(g) affecting the attainment of that use;

(d) a description of the data being proposed to be used to demonstrate the highest attainable use;

(e) the provisions for consultation with appropriate state and federal agencies;

(f) a description of how stakeholders and potentially affected tribes will be identified and engaged;

(g) a description of the public notice mechanisms to be employed; and

(h) the expected timelines outlining the administrative actions to be taken for a rulemaking petition, pending the outcome of the use attainability analysis.

(4) Upon completion of the use attainability analysis, the proponent shall submit the data, findings and conclusions to the department, and provide public notice of the use attainability analysis in accordance with the approved work plan.

(5) Pending the conclusions of the use attainability analysis and as described in the approved work plan, the department or the proponent may petition the commission to modify the designated use. The cost of such use attainability analysis shall be the responsibility of the proponent. Subsequent costs associated with the administrative rulemaking process shall be the responsibility of the petitioner.
[20.6.4.15 NMAC - Rp 20 NMAC 6.1.1107, 10/12/2000; Rn, 20.6.4.14 NMAC, 5/23/2005; A, 5/23/2005; A, 7/17/2005; A, 12/1/2010; A, 4/23/2022]

20.6.4.16 PLANNED USE OF A PISCICIDE: The use of a piscicide registered under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), 7 U.S.C. Section 136 *et seq*., and under the New Mexico Pesticide Control Act (NMPCA), Section 76-4-1 *et seq*. NMSA 1978 (1973) in a surface water of the state, shall not be a violation of Subsection F of 20.6.4.13 NMAC when such use is covered by a federal national pollutant discharge elimination system (NPDES) permit or has been approved by the commission under procedures provided in this section. The use of a piscicide which is covered by a NPDES permit shall require no further review by the commission and the person whose application is covered by the NPDES permit shall meet the additional notification and monitoring requirements outlined in Subsection G of 20.6.4.16 NMAC. The commission may approve the reasonable use of a piscicide under this section if the proposed use is not covered by a NPDES permit to further a Clean Water Act objective to restore and maintain the physical or biological integrity of surface waters of the state, including restoration of native species.

A. Any person seeking commission approval of the use of a piscicide not covered by a NPDES permit shall file a written petition concurrently with the commission and the surface water bureau of the department. The petition shall contain, at a minimum, the following information:

(1) petitioner’s name and address;

(2) identity of the piscicide and the period of time (not to exceed five years) or number of applications for which approval is requested;

(3) documentation of registration under FIFRA and NMPCA and certification that the petitioner intends to use the piscicide according to the label directions, for its intended function;

(4) target and potential non-target species in the treated waters and adjacent riparian area, including threatened or endangered species;

(5) potential environmental consequences to the treated waters and the adjacent riparian area, and protocols for limiting such impacts;

(6) surface water of the state proposed for treatment;

(7) results of pre-treatment survey;

(8) evaluation of available alternatives and justification for selecting piscicide use;

(9) documentation of notice requesting public comment on the proposed use within a 30-day period, including information as described in Paragraphs (1), (2) and (6) of Subsection A of 20.6.4.16 NMAC, provided to:

(a) local political subdivisions;

(b) local water planning entities;

(c) local conservancy and irrigation districts; and

(d) local media outlets, except that the petitioner shall only be required to publish notice in a newspaper of circulation in the locality affected by the proposed use.

(10) copies of public comments received in response to the publication of notice and the petitioner’s responses to public comments received;

(11) post-treatment assessment monitoring protocol; and

(12) any other information required by the commission.

B. Within 30 days of receipt of the petition, the department shall review the petition and file a recommendation with the commission to grant, grant with conditions or deny the petition. The recommendation shall include reasons, and a copy shall be sent to the petitioner by certified mail.

C. The commission shall review the petition, the public comments received under Paragraphs (9) and (10) of Subsection A of 20.6.4.16 NMAC, the petitioner’s responses to public comments and the department’s technical recommendations for the petition. A public hearing shall be held if the commission determines there is substantial public interest. The commission shall notify the petitioner and those commenting on the petition of the decision whether to hold a hearing and the reasons therefore in writing.

D. If the commission determines there is substantial public interest a public hearing shall be held within 90 days of receipt of the department’s recommendation in the locality affected by the proposed use in accordance with 20.1.3 NMAC, Adjudicatory Procedures - Water Quality Control Commission. Notice of the hearing shall be given in writing by the petitioner to individuals listed under Subsection A of 20.6.4.16 NMAC as well as to individuals who provided public comment under that subsection at least 30 days prior to the hearing.

E. In a hearing provided for in this section or, if no hearing is held, in a commission meeting, the registration of a piscicide under FIFRA and NMPCA shall provide a rebuttable presumption that the determinations of the EPA Administrator in registering the piscicide, as outlined in 7 U.S.C. Section 136a(c)(5), are valid. For purposes of this Section the rebuttable presumptions regarding the piscicide include:

(1) Its composition is such as to warrant the proposed claims for it;

(2) Its labeling and other material submitted for registration comply with the requirements of FIFRA and NMPCA;

(3) It will perform its intended function without unreasonable adverse effects on the environment; and

(4) When used in accordance with all FIFRA label requirements it will not generally cause unreasonable adverse effects on the environment.

(5) "Unreasonable adverse effects on the environment" has the meaning provided in FIFRA, 7 U.S.C. Section 136(bb): "any unreasonable risk to man or the environment, taking into account the economic, social, and environmental costs and benefits of the use of any pesticide."

F. After a public hearing, or commission meeting if no hearing is held, the commission may grant the petition in whole or in part, may grant the petition subject to conditions, or may deny the petition. In granting any petition in whole or part or subject to conditions, the commission shall require the petitioner to implement post-treatment assessment monitoring and provide notice to the public in the immediate and near downstream vicinity of the application prior to and during the application.

G. Any person whose application is covered by a NPDES permit shall provide written notice to local entities as described in Subsection A of 20.6.4.16 NMAC and implement post-treatment assessment monitoring within the application area as described in Subsection F of 20.6.4.16 NMAC.

[20.6.4.16 NMAC - Rn, Paragraph (6) of Subsection F of 20.6.4.12 NMAC, 5/23/2005; A, 5/23/2005; A, 3/2/2017]

20.6.4.17 - 20.6.4.49 [**RESERVED**]

20.6.4.50 BASINWIDE PROVISIONS - Special provisions arising from interstate compacts, international treaties or court decrees or that otherwise apply to a basin are contained in 20.6.4.51 through 20.6.4.59 NMAC.

[20.6.4.50 NMAC - N, 5/23/2005]

20.6.4.51 [**RESERVED**]

20.6.4.52 PECOS RIVER BASIN - In order to protect existing and designated uses, it is a goal of the state of New Mexico to prevent increases in TDS in the Pecos river above the following benchmark values, which are expressed as flow-weighted, annual average concentrations, at three USGS gaging stations: at Santa Rosa 500 mg/L; near Artesia 2,700 mg/L; and near Malaga 3,600 mg/L. The benchmark values serve to guide state action. They are adopted pursuant to the New Mexico Water Quality Act, not the Clean Water Act.

[20.6.4.52 NMAC - N, 12/1/2010]

20.6.4.53 [**RESERVED**]

20.6.4.54 COLORADO RIVER BASIN - For the tributaries of the Colorado river system, the state of New Mexico will cooperate with the Colorado river basin states and the federal government to support and implement the salinity policy and program outlined in the most current "review, water quality standards for salinity, Colorado river system" or equivalent report by the Colorado river salinity control forum.

A. Numeric criteria expressed as the flow-weighted annual average concentration for salinity are established at three points in the Colorado river basin as follows: below Hoover dam, 723 mg/L; below Parker dam, 747 mg/L; and at Imperial dam, 879 mg/L.

B. As a part of the program, objectives for New Mexico shall include the elimination of discharges of water containing solids in solution as a result of the use of water to control or convey fly ash from coal-fired electric generators, wherever practicable.

[20.6.4.54 NMAC - Rn, Paragraphs (1) through (3) of Subsection K of 20.6.4.12 NMAC, 5/23/2005; A, 5/23/2005]

20.6.4.55 - 20.6.4.96 [**RESERVED**]

20.6.4.97 EPHEMERAL WATERS: Ephemeral surface waters of the state as identified below and additional ephemeral waters as identified on the department's water quality standards website pursuant to Paragraph (2) of Subsection D of 20.6.4.15 NMAC are subject to the designated uses and criteria as specified in this section. Ephemeral waters classified in 20.6.4.101-899 NMAC are subject to the designated uses and criteria as specified in those sections.

A. Designated uses: livestock watering, wildlife habitat, limited aquatic life and secondary contact.

B. Criteria: the use-specific criteria in 20.6.4.900 NMAC are applicable to the designated uses.

C. Waters:

(1) the following waters are designated in the Rio Grande basin:

(a) Cunningham gulch from Santa Fe county road 55 upstream 1.4 miles to a point upstream of the Lac minerals mine, identified as Ortiz mine on U.S. geological survey topographic maps;

(b) an unnamed tributary from Arroyo Hondo upstream 0.4 miles to the Village of Oshara water reclamation facility outfall;

(c) an unnamed tributary from San Pedro creek upstream 0.8 miles to the PAA-KO community sewer outfall;

(d) Inditos draw from the crossing of an unnamed road along a power line one-quarter mile west of McKinley county road 19 upstream to New Mexico highway 509;

(e) an unnamed tributary from the diversion channel connecting Blue canyon and Socorro canyon upstream 0.6 miles to the New Mexico firefighters academy treatment facility outfall;

(f) an unnamed tributary from the Albuquerque metropolitan arroyo flood control authority (AMAFCA) Rio Grande south channel upstream of the crossing of New Mexico highway 47 upstream to I-25;

(g) the south fork of Cañon del Piojo from Cañon del Piojo upstream 1.2 miles to an unnamed tributary;

(h) an unnamed tributary from the south fork of Cañon del Piojo upstream 1 mile to the Resurrection mine outfall;

(i) Arroyo del Puerto from San Mateo creek upstream 6.8 miles to the Ambrosia Lake mine entrance road;

(j) an unnamed tributary from San Mateo creek upstream 1.5 miles to the Roca Honda mine facility outfall;

(k) San Isidro arroyo, including unnamed tributaries to San Isidro arroyo, from Arroyo Chico upstream to its headwaters;

(l) Arroyo Tinaja, including unnamed tributaries to Arroyo Tinaja, from San Isidro arroyo upstream to 2 miles northeast of the Cibola national forest boundary;

(m) Mulatto canyon from Arroyo Tinaja upstream to 1 mile northeast of the Cibola national forest boundary; and

(n) Doctor arroyo, including unnamed tributaries to Doctor arroyo, from San Isidro arroyo upstream to its headwaters, and excluding Doctor Spring and Doctor arroyo from the spring to its confluence with the unnamed tributary approximately one-half mile downstream of the spring.

(2) the following waters are designated in the Pecos river basin:

(a) an unnamed tributary from Hart canyon upstream 1 mile to South Union road;

(b) Aqua Chiquita from Rio Peñasco upstream to McEwan canyon; and

(c) Grindstone canyon upstream of Grindstone reservoir.

(3) the following waters are designated in the Canadian river basin:

(a) Bracket canyon upstream of the Vermejo river;

(b) an unnamed tributary from Bracket canyon upstream 2 miles to the Ancho mine; and

(c) Gachupin canyon from the Vermejo river upstream 2.9 miles to an unnamed west tributary near the Ancho mine outfall.

(4) in the San Juan river basin an unnamed tributary of Kim-me-ni-oli wash upstream of the mine outfall.

(5) the following waters are designated in the Little Colorado river basin:

(a) Defiance draw from County Road 1 to upstream of West Defiance Road; and

(b) an unnamed tributary of Defiance draw from McKinley county road 1 upstream to New Mexico highway 264.

(6) the following waters are designated in the closed basins:

(a) in the Tularosa river closed basin San Andres canyon downstream of South San Andres canyon; and

(b) in the Mimbres river closed basin San Vicente arroyo from the Mimbres river upstream to Maudes canyon.

[20.6.4.97 NMAC - N, 5/23/2005; A, 12/1/2010; A, 3/2/2017; A, 12/17/2019; A, 4/23/2022]

20.6.4.98 INTERMITTENT WATERS: All non-perennial surface waters of the state, except those ephemeral waters included under section 20.6.4.97 NMAC or classified in 20.6.4.101-899 NMAC.

A. Designated uses: livestock watering, wildlife habitat, marginal warmwater aquatic life and primary contact.

B. Criteria: the use-specific criteria in 20.6.4.900 NMAC are applicable to the designated uses, except that the following site-specific criteria apply: the monthly geometric mean of E. coli bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

[20.6.4.98 NMAC - N, 5/23/2005; A, 12/1/2010; A, 3/2/2017]

20.6.4.99 PERENNIAL WATERS: All perennial surface waters of the state except those classified in 20.6.4.101-899 NMAC.

A. Designated uses: Warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: The use-specific criteria in 20.6.4.900 NMAC are applicable to the designated uses, except that the following site-specific criteria apply: the monthly geometric mean of E. coli bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

[20.6.4.99 NMAC - N, 5/23/2005; A, 12/1/2010; A, 3/2/2017]

20.6.4.100 [**RESERVED**]

20.6.4.101 RIO GRANDE BASIN: The main stem of the Rio Grande from the international boundary with Mexico upstream to one mile downstream of Percha dam.

A. Designated uses: irrigation, marginal warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criterion applies: temperature 34°C (93.2°F) or less.

(2) At mean monthly flows above 350 cfs, the monthly average concentration for: TDS 2,000 mg/L or less, sulfate 500 mg/L or less and chloride 400 mg/L or less.

C. Remarks: sustained flow in the Rio Grande below Caballo reservoir is dependent on release from Caballo reservoir during the irrigation season; at other times of the year, there may be little or no flow.

[20.6.4.101 NMAC - Rp 20 NMAC 6.1.2101, 10/12/2010; A, 12/15/2001; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017]

20.6.4.102 RIO GRANDE BASIN: The main stem of the Rio Grande from one mile downstream of Percha dam upstream to Caballo dam.

A. Designated uses: irrigation, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

C. Remarks: sustained flow in the Rio Grande downstream of Caballo reservoir is dependent on release from Caballo reservoir during the irrigation season; at other times of the year, there may be little or no flow.

[20.6.4.102 NMAC - Rp 20 NMAC 6.1.2102, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017]

20.6.4.103 RIO GRANDE BASIN: Perennial reaches of tributaries to the Rio Grande in Sierra and Socorro counties not specifically identified under other sections of 20.6.4 NMAC, excluding waters on tribal lands.

A. **Designated uses:** irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life, secondary contact and warmwater aquatic life.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.103 NMAC - Rp 20 NMAC 6.1.2103, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

[**NOTE:** This segment was divided effective 4/23/2022. The standards for the main stem of the Rio Grande from the headwaters of Caballo reservoir upstream to Elephant Butte dam, perennial reaches of Palomas creek, perennial reaches of Rio Salado, perennial reaches of Percha creek, perennial reaches of Alamosa creek, Las Animas creek, and perennial reaches of Abo arroyo are under 20.6.4.112 NMAC.]

20.6.4.104 RIO GRANDE BASIN: Caballo and Elephant Butte reservoir.

A. **Designated uses:** irrigation storage, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.104 NMAC - Rp 20 NMAC 6.1.2104, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.105 RIO GRANDE BASIN: The main stem of the Rio Grande from the headwaters of Elephant Butte reservoir upstream to Alameda bridge (Corrales bridge), excluding waters on Isleta pueblo.

A. **Designated uses:** irrigation, marginal warmwater aquatic life, livestock watering, public water supply, wildlife habitat and primary contact.

B. **Criteria:**

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At mean monthly flows above 100 cfs, the monthly average concentration for: TDS l,500 mg/L or less, sulfate 500 mg/L or less and chloride 250 mg/L or less.

[20.6.4.105 NMAC - Rp 20 NMAC 6.1.2105, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.106 RIO GRANDE BASIN: The main stem of the Rio Grande from Alameda bridge (Corrales bridge) upstream to the Angostura diversion works, excluding waters on Santa Ana pueblo, and intermittent water in the Jemez river below the Jemez pueblo boundary, excluding waters on Santa Ana and Zia pueblos, that enters the main stem of the Rio Grande. Portions of the Rio Grande in this segment are under the joint jurisdiction of the state and Sandia pueblo.

A. **Designated uses:** irrigation, marginal warmwater aquatic life, livestock watering, wildlife habitat and primary contact; and public water supply on the Rio Grande.

B. **Criteria:**

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At mean monthly flows above 100 cfs, the monthly average concentration for: TDS 1,500 mg/L or less, sulfate 500 mg/L or less and chloride 250 mg/L or less.

[20.6.4.106 NMAC - Rp 20 NMAC 6.1.2105.1, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.107 RIO GRANDE BASIN: The Jemez river from the Jemez pueblo boundary upstream to Soda dam near the town of Jemez Springs and perennial reaches of Vallecito creek.

A. **Designated uses:** coldwater aquatic life, primary contact, irrigation, livestock watering and wildlife habitat; and public water supply on Vallecito creek.

B. **Criteria:** The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F).

[20.6.4.107 NMAC - Rp 20 NMAC 6.1.2105.5, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.108 RIO GRANDE BASIN: Perennial reaches of the Jemez river upstream of Soda dam near the town of Jemez Springs and perennial reaches of tributaries to the Jemez river except those not specifically identified under other sections of 20.6.4 NMAC, and perennial reaches of the Guadalupe river and perennial reaches of tributaries to the Guadalupe river, and Calaveras canyon.

A. Designated uses: domestic water supply, fish culture, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 400 µS/cm or less (800 µS/cm or less on Sulphur creek); the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less; and pH within the range of 2.0 to 8.8 on Sulphur creek.

[20.6.4.108 NMAC - Rp 20 NMAC 6.1.2106, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 7/10/2012; A, 4/23/2022]

[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for the additional segment are under 20.6.4.124 NMAC. The standards for San Gregorio lake are in 20.6.4.134 NMAC, effective 7/10/2012]

20.6.4.109 RIO GRANDE BASIN: Perennial reaches of Bluewater creek excluding Bluewater lake and waters on tribal lands, Rio Moquino upstream of Laguna pueblo, Seboyeta creek, Rio Paguate upstream of Laguna pueblo, the Rio Puerco upstream of the northern boundary of Cuba, and all other perennial reaches of tributaries to the Rio Puerco, including the Rio San Jose in Cibola county from the USGS gaging station at Correo upstream to Horace springs excluding waters on tribal lands.

A. Designated uses: coldwater aquatic life, domestic water supply, fish culture, irrigation, livestock watering, wildlife habitat and primary contact; and public water supply on La Jara creek.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: phosphorus (unfiltered sample) 0.1 mg/L or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.109 NMAC - Rp 20 NMAC 6.1.2107, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 7/10/2012]

[**NOTE:** The standards for Bluewater lake are in 20.6.4.135 NMAC, effective 7/10/2012]

20.6.4.110 RIO GRANDE BASIN: The main stem of the Rio Grande from Angostura diversion works upstream to Cochiti dam, excluding the reaches on San Felipe, Kewa and Cochiti pueblos.

A. Designated uses: irrigation, livestock watering, wildlife habitat, primary contact, coldwater aquatic life and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: pH within the range of 6.6 to 9.0 and temperature 25°C (77°F) or less.

[20.6.4.110 NMAC - Rp 20 NMAC 6.1.2108, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017]

20.6.4.111 RIO GRANDE BASIN: Perennial reaches of Las Huertas creek from the San Felipe pueblo boundary to the headwaters.

A. Designated uses: high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F) or less.

[20.6.4.111 NMAC - Rp 20 NMAC 6.1.2108.5, 10/12/2000; A, 7/25/2001; A, 5/23/2005; A-12/1/2010]

[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for the additional segment are under 20.6.4.125 NMAC.]

20.6.4.112 RIO GRANDE BASIN: The main stem of the Rio Grande from the headwaters of Caballo reservoir upstream to Elephant Butte dam, perennial reaches of Palomas creek, perennial reaches of Rio Salado, perennial reaches of Percha creek, perennial reaches of Alamosa creek, Las Animas creek, and perennial reaches of Abo arroyo.

A. Designated uses: irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life, primary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

C. Remarks: flow in this reach of the Rio Grande main stem is dependent upon release from Elephant Butte dam.

[20.6.4.112 NMAC - Rp 20 NMAC 6.1.2109, 10/12/2000; A, 5/23/2005; Repealed, 12/1/2010; A, 4/23/2022]

20.6.4.113 RIO GRANDE BASIN: The Santa Fe river and perennial reaches of its tributaries from the Cochiti pueblo boundary upstream to the outfall of the Santa Fe wastewater treatment facility.

A. Designated uses: irrigation, livestock watering, wildlife habitat, primary contact and coolwater aquatic life.

B. Criteria: The use-specific criteria in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 30°C (86°F) or less.

[20.6.4.113 NMAC - Rp 20 NMAC 6.1.2110, 10/12/2000; A, 10/11/2002; A, 5/23/2005; A, 12/1/2010; A, 2/14/2013]

20.6.4.114 RIO GRANDE BASIN: The main stem of the Rio Grande from the Cochiti pueblo boundary upstream to Rio Pueblo de Taos excluding waters on San Ildefonso, Santa Clara and Ohkay Owingeh pueblos, Embudo creek from its mouth on the Rio Grande upstream to the Picuris Pueblo boundary, the Santa Cruz river from the Santa Clara pueblo boundary upstream to the Santa Cruz dam, the Rio Tesuque except waters on the Tesuque and Pojoaque pueblos, and the Pojoaque river from the San Ildefonso pueblo boundary upstream to the Pojoaque pueblo boundary. Some Rio Grande waters in this segment are under the joint jurisdiction of the state and San Ildefonso pueblo.

A. Designated uses: irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life, primary contact and warmwater aquatic life; and public water supply on the main stem Rio Grande.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: 6T3 temperature 22°C (71.6°F) and maximum temperature 25°C (78.8°F). In addition, the following criteria based on a 12-month rolling average are applicable to the public water supply use for monitoring and public disclosure purposes only:

Radionuclide	pCi/L
Americium-241	1.9
Cesium-137	6.4
Plutonium-238	1.5
Plutonium-239/240	1.5
Strontium-90	3.5
Tritium	4,000

(2) At mean monthly flows above 100 cfs, the monthly average concentration for: TDS 500 mg/L or less, sulfate 150 mg/L or less and chloride 25 mg/L or less.

[20.6.4.114 NMAC - Rp 20 NMAC 6.1.2111, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.115 RIO GRANDE BASIN: The perennial reaches of Rio Vallecitos, perennial reaches of tributaries to Rio Vallecitos except Hopewell lake, and perennial reaches of Rio del Oso and perennial reaches of El Rito creek above the town of El Rito.

A. Designated uses: domestic water supply, irrigation, high quality coldwater aquatic life, livestock watering, wildlife habitat and primary contact; public water supply on the Rio Vallecitos and El Rito creek.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.115 NMAC - Rp 20 NMAC 6.1.2112, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 7/10/2012; A, 4/23/2022]

[**NOTE:** The standards for Hopewell lake are in 20.6.4.134 NMAC, effective 7/10/2012]

20.6.4.116 RIO GRANDE BASIN: The Rio Chama from its mouth on the Rio Grande upstream to Abiquiu reservoir, perennial reaches of the Rio Tusas, perennial reaches of the Rio Ojo Caliente, perennial reaches of Abiquiu creek and perennial reaches of El Rito creek downstream of the town of El Rito.

A. Designated uses: irrigation, livestock watering, wildlife habitat, coldwater aquatic life, warmwater aquatic life and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 31°C (87.8°F) or less.

[20.6.4.116 NMAC - Rp 20 NMAC 6.1.2113, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017; A, 4/23/2022]

20.6.4.117 RIO GRANDE BASIN: Abiquiu reservoir.

A. Designated uses: irrigation storage, livestock watering, wildlife habitat, primary contact, coldwater aquatic life and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F) or less.

[20.6.4.117 NMAC - Rp 20 NMAC 6.1.2114, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.118 RIO GRANDE BASIN: The Rio Chama from the headwaters of Abiquiu reservoir upstream to El Vado reservoir and perennial reaches of the Rio Gallina and Rio Puerco de Chama north of state highway 96. Some Rio Chama waters in this segment are under the joint jurisdiction of the state and the Jicarilla Apache tribe.

A. Designated uses: irrigation, livestock watering, wildlife habitat, coldwater aquatic life, warmwater aquatic life and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 26°C (78.8°F) or less.

[20.6.4.118 NMAC - Rp 20 NMAC 6.1.2115, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.119 RIO GRANDE BASIN: All perennial reaches of tributaries to the Rio Chama above Abiquiu dam, except Canjilon lakes a, c, e and f and the Rio Gallina and Rio Puerco de Chama north of state highway 96 and excluding waters on Jicarilla Apache reservation, and the main stem of the Rio Chama from the headwaters of El Vado reservoir upstream to the New Mexico-Colorado line. Some Cañones creek and Rio Chama waters in this segment are under the joint jurisdiction of the state and the Jicarilla Apache tribe.

A. Designated uses: domestic water supply, fish culture, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact; and public water supply on the Rio Brazos and Rio Chama.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 500 µS/cm or less (1,000 µS or less for Coyote creek); the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.119 NMAC - Rp 20 NMAC 6.1.2116, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 7/10/2012]

[**NOTE:** The standards for Canjilon lakes a, c, e and f are in 20.6.4.134 NMAC, effective 7/10/2012]

20.6.4.120 RIO GRANDE BASIN: El Vado and Heron reservoirs.

A. Designated uses: irrigation storage, livestock watering, wildlife habitat, public water supply, primary contact and coldwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.120 NMAC - Rp 20 NMAC 6.1.2117, 10/12/2000; A. 5/23/2005; A, 12/1/2010]

20.6.4.121 RIO GRANDE BASIN: Perennial tributaries to the Rio Grande in Bandelier national monument and their headwaters in Sandoval county and all perennial reaches of tributaries to the Rio Grande in Santa Fe county unless included in other segments and excluding waters on tribal lands.

A. Designated uses: domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact; and public water supply on Little Tesuque creek, the Rio en Medio, and the Santa Fe river.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.121 NMAC - Rp 20 NMAC 6.1.2118, 10/12/2000; A. 5/23/2005; A, 12/1/2010; A, 2/14/2013]

[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for the additional segments are under 20.6.4.126, 20.6.4.127 and 20.6.4.128 NMAC.]

20.6.4.122 RIO GRANDE BASIN: The main stem of the Rio Grande from Rio Pueblo de Taos upstream to the New Mexico-Colorado line, the Red river from its mouth on the Rio Grande upstream to the

mouth of Placer creek, and the Rio Pueblo de Taos from its mouth on the Rio Grande upstream to the mouth of the Rio Grande del Rancho. Some Rio Grande and Rio Pueblo de Taos waters in this segment are under the joint jurisdiction of the state and Taos pueblo.

A. Designated uses: coldwater aquatic life, fish culture, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.122 NMAC - Rp 20 NMAC 6.1.2119, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.123 RIO GRANDE BASIN: Perennial reaches of the Red river upstream of the mouth of Placer creek, all perennial reaches of tributaries to the Red river, and all other perennial reaches of tributaries to the Rio Grande in Taos and Rio Arriba counties unless included in other segments and excluding waters on Santa Clara, Ohkay Owingeh, Picuris and Taos pueblos.

A. Designated uses: domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact; and public water supply on the Rio Pueblo and Rio Fernando de Taos.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 400 µS/cm or less (500 µS/cm or less for the Rio Fernando de Taos); the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less; and phosphorus (unfiltered sample) less than 0.1 mg/L for the Red river.

[20.6.4.123 NMAC - Rp 20 NMAC 6.1.2120, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for the additional segment are under 20.6.4.129 NMAC.]

20.6.4.124 RIO GRANDE BASIN: Perennial reaches of Sulphur creek from its confluence with Redondo creek upstream to its headwaters.

A. Designated uses: limited aquatic life, wildlife habitat, livestock watering and secondary contact.

B. Criteria: the use-specific criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: pH within the range of 2.0 to 9.0, maximum temperature 30ºC (86ºF), and the chronic aquatic life criteria of Subsections I and J of 20.6.4.900 NMAC.

[20.6.4.124 NMAC - N, 5/23/2005; A, 12/1/2010; A, 3/2/2017]

20.6.4.125 RIO GRANDE BASIN: Perennial reaches of San Pedro creek from the San Felipe pueblo boundary to the headwaters.

A. Designated uses: coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F) or less.

[20.6.4.125 NMAC - N, 5/23/2005; A, 12/1/2010]

20.6.4.126 RIO GRANDE BASIN: Perennial waters within lands managed by the U.S. department of energy (DOE) within Los Alamos National Laboratory (LANL), including but not limited to: Cañon de Valle from LANL stream gage E256 upstream to Burning Ground spring, Sandia canyon from Sigma canyon upstream to LANL NPDES outfall 001, Pajarito canyon from 0.5 miles below Arroyo de La Delfe upstream to Homestead spring, Arroyo de la Delfe from Pajarito canyon to Kieling spring, Starmers gulch and Starmers spring and Water canyon from Area-A canyon upstream to State Route 501.

A. Designated uses: coldwater aquatic life, livestock watering, wildlife habitat and secondary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.126 NMAC - N, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

20.6.4.127 RIO GRANDE BASIN: Perennial portions of Los Alamos canyon upstream from Los Alamos reservoir and Los Alamos reservoir.

A. **Designated uses:** coldwater aquatic life, livestock watering, wildlife habitat, irrigation and primary contact.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.127 NMAC - N, 5/23/2005; A, 12/1/2010]

20.6.4.128 RIO GRANDE BASIN: Ephemeral and intermittent waters within lands managed by U.S. department of energy (DOE) within LANL, including but not limited to: Mortandad canyon, Cañada del Buey, Ancho canyon, Chaquehui canyon, Indio canyon, Fence canyon, Potrillo canyon, and portions of Cañon de Valle, Los Alamos canyon, Sandia canyon, Pajarito canyon and Water canyon not identified in 20.6.4.126 NMAC or 20.6.4.140 NMAC. (Surface waters within lands scheduled for transfer from DOE to tribal, state or local authorities are specifically excluded.)

A. **Designated uses:** livestock watering, wildlife habitat, limited aquatic life and secondary contact.

B. **Criteria:** the use-specific criteria in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the acute total ammonia criteria set forth in Subsection L of 20.6.4.900 NMAC (*Oncorhynchus* spp. absent).

[20.6.4.128 NMAC - N, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

[**NOTE:** This section was divided effective 4/23/2022. The standards for some intermittent waters within LANL are in 20.6.4.140 NMAC.]

20.6.4.129 RIO GRANDE BASIN: Perennial reaches of the Rio Hondo.

A. **Designated uses:** domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 400 µS/cm or less and phosphorus (unfiltered sample) less than 0.1 mg/L.

[20.6.4.129 NMAC - N, 5/23/2005; A, 12/1/2010]

20.6.4.130 RIO GRANDE BASIN: The Rio Puerco from the Rio Grande upstream to Arroyo Chijuilla, excluding the reaches on Isleta, Laguna and Cañoncito Navajo pueblos. Some waters in this segment are under the joint jurisdiction of the state and Isleta, Laguna or Cañoncito Navajo pueblos.

A. **Designated uses:** irrigation, warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. **Criteria:**

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At mean monthly flows above 100 cfs, the monthly average concentration for: TDS l,500 mg/L or less, sulfate 500 mg/L or less and chloride 250 mg/L or less.

[20.6.4.130 NMAC - N, 12/1/2010]

20.6.4.131 RIO GRANDE BASIN: The Rio Puerco from the confluence of Arroyo Chijuilla upstream to the northern boundary of Cuba.

A. **Designated uses:** warmwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.131 NMAC - N, 12/1/2010]

20.6.4.132 RIO GRANDE BASIN: Rio Grande (Klauer) spring

A. **Designated uses:** domestic water supply, wildlife habitat, livestock watering, coldwater aquatic life use and primary contact.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.132 NMAC - N, 12/1/2010]

20.6.4.133 RIO GRANDE BASIN: Bull Creek lake, Cow lake, Elk lake, Goose lake, Heart lake, Hidden lake (Lake Hazel), Horseshoe lake, Horseshoe (Alamitos) lake, Jose Vigil lake, Lost lake, Middle Fork lake, Nambe lake, Nat II lake, Nat IV lake, No Fish lake, Pioneer lake, San Leonardo lake, Santa Fe lake, Serpent lake, South Fork lake, Trampas lakes (east and west) and Williams lake.

A. Designated uses: high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.133 NMAC - N, 7/10/2012]

20.6.4.134 RIO GRANDE BASIN: Cabresto lake, Canjilon lakes a, c, e and f, Fawn lakes (east and west), Hopewell lake and San Gregorio lake.

A. Designated uses: high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.134 NMAC - N, 7/10/2012]

20.6.4.135 RIO GRANDE BASIN: Bluewater lake.

A. Designated uses: coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: phosphorus (unfiltered sample) 0.1 mg/L or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.135 NMAC - N, 7/10/2012]

20.6.4.136 RIO GRANDE BASIN: The Santa Fe river from the outfall of the Santa Fe wastewater treatment facility to Guadalupe street.

A. Designated uses: limited aquatic life, wildlife habitat, primary contact, livestock watering, and irrigation.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.136 NMAC - N, 2/14/2013]

20.6.4.137 RIO GRANDE BASIN: The Santa Fe river from Guadalupe street to Nichols reservoir.

A. Designated uses: coolwater aquatic life, wildlife habitat, primary contact, livestock watering, and irrigation.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.137 NMAC - N, 2/14/2013]

20.6.4.138 RIO GRANDE BASIN: Nichols and McClure reservoirs.

A. Designated uses: high quality coldwater aquatic life, wildlife habitat, primary contact, public water supply and irrigation.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.138 NMAC - N, 2/14/2013]

20.6.4.139 RIO GRANDE BASIN: Perennial reaches of Galisteo creek and perennial reaches of its tributaries from Kewa pueblo upstream to 2.2 miles upstream of Lamy.

A. Designated uses: coolwater aquatic life, primary contact, irrigation, livestock watering, domestic water supply and wildlife habitat; and public water supply on Cerrillos reservoir.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.
[20.6.4.139 NMAC - N, 2/14/2013]

20.6.4.140 RIO GRANDE BASIN: Effluent canyon from Mortandad canyon to its headwaters, intermittent portions of S-Site canyon from monitoring well MSC 16-06293 to Martin spring, and intermittent portions of Twomile canyon from its confluence with Pajarito canyon to Upper Twomile canyon. (Surface waters within lands scheduled for transfer from DOE to tribal, state or local authorities are specifically excluded.)

A. **Designated uses:** livestock watering, wildlife habitat, marginal warmwater aquatic life and secondary contact.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.
[20.6.4.140 NMAC - N, 4/23/2022]

20.6.4.141 - 20.6.4.200 [**RESERVED**]

20.6.4.201 PECOS RIVER BASIN: The main stem of the Pecos river from the New Mexico-Texas line upstream to the mouth of the Black river (near Loving).

A. **Designated uses:** irrigation, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. **Criteria:**

(l) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: dissolved boron for irrigation use 2,000 µg/L or less.

(2) At all flows above 50 cfs: TDS 20,000 mg/L or less, sulfate 3,000 mg/L or less and chloride 10,000 mg/L or less.
[20.6.4.201 NMAC - Rp 20 NMAC 6.1.2201, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.202 PECOS RIVER BASIN: The main stem of the Pecos river from the mouth of the Black river upstream to lower Tansil dam, including perennial reaches of the Black river, the Delaware river and Blue spring.

A. **Designated uses:** industrial water supply, irrigation, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. **Criteria:**

(l) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 34°C (93.2°F) or less.

(2) At all flows above 50 cfs: TDS 8,500 mg/L or less, sulfate 2,500 mg/L or less and chloride 3,500 mg/L or less.

C. **Remarks:** diversion for irrigation frequently limits summer flow in this reach of the main stem Pecos river to that contributed by springs along the watercourse.
[20.6.4.202 NMAC - Rp 20 NMAC 6.1.2202, 10/12/2000; A, 5/23/2005; A, 12/1/2010]
[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for Lower Tansil Lake and Lake Carlsbad are under 20.6.4.218 NMAC.]

20.6.4.203 PECOS RIVER BASIN: The main stem of the Pecos river from the headwaters of Lake Carlsbad upstream to Avalon dam.

A. **Designated uses:** industrial water supply, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: temperature 34°C (93.2°F) or less; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.
[20.6.4.203 NMAC - Rp 20 NMAC 6.1.2203, 10/12/2000; A, 5/23/2005; A, 12/1/2010]
[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for Lower Tansil Lake and Lake Carlsbad are under 20.6.4.218 and for Avalon Reservoir are under 20.6.4.219 NMAC.]

20.6.4.204 PECOS RIVER BASIN: The main stem of the Pecos river from the headwaters of Avalon reservoir upstream to Brantley dam.

A. Designated uses: irrigation, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.204 NMAC - Rp 20 NMAC 6.1.2204, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for Avalon Reservoir are under 20.6.4.219 NMAC.]

20.6.4.205 PECOS RIVER BASIN: Brantley reservoir.

A. Designated uses: irrigation storage, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.205 NMAC - Rp 20 NMAC 6.1.2205, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.206 PECOS RIVER BASIN: Perennial reaches of the Rio Felix and perennial reaches of tributaries to the Rio Hondo downstream of Bonney canyon, excluding North Spring river.

A. Designated uses: irrigation, livestock watering, wildlife habitat, secondary contact and warmwater aquatic life.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 14,000 mg/L or less, sulfate 3,000 mg/L or less and chloride 6,000 mg/L or less.

[20.6.4.206 NMAC - Rp 20 NMAC 6.1.2206, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017; A, 4/23/2022]

[**NOTE:** This segment was divided effective 4/23/2022. The standards for the main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from state highway 24 near Dunken, and perennial reaches of the Rio Hondo are under 20.6.4.231 NMAC.]

20.6.4.207 PECOS RIVER BASIN: The main stem of the Pecos river from Salt creek (near Acme) upstream to Sumner dam.

A. Designated uses: irrigation, marginal warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 8,000 mg/L or less, sulfate 2,500 mg/L or less and chloride 4,000 mg/L or less.

[20.6.4.207 NMAC - Rp 20 NMAC 6.1.2207, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

20.6.4.208 PECOS RIVER BASIN: Perennial reaches of the Rio Peñasco above state highway 24 near Dunken, perennial reaches of tributaries to the Rio Peñasco above state highway 24 near Dunken, perennial reaches of Cox canyon, perennial reaches of the Rio Bonito downstream from state highway 48 (near Angus), the Rio Ruidoso downstream of the U.S. highway 70 bridge near Seeping Springs lakes, perennial reaches of the Rio Hondo upstream from Bonney canyon and perennial reaches of Agua Chiquita.

A. Designated uses: fish culture, irrigation, livestock watering, wildlife habitat, coldwater aquatic life and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: temperature 30°C (86°F) or less, and phosphorus (unfiltered sample) less than 0.1 mg/L.

[20.6.4.208 NMAC - Rp 20 NMAC 6.1.2208, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

20.6.4.209 PECOS RIVER BASIN: Perennial reaches of Eagle creek upstream of Alto dam to the Mescalero Apache boundary, perennial reaches of the Rio Bonito upstream of state highway 48 (near Angus) excluding Bonito lake, perennial reaches of tributaries to the Rio Bonito upstream of state highway 48 (near Angus), perennial reaches of the Rio Ruidoso upstream of the U.S. highway 70 bridge near Seeping Springs lakes above and below the Mescalero Apache boundary and perennial reaches of tributaries to the Rio Ruidoso upstream of the U.S. highway 70 bridge near Seeping Springs lakes above and below the Mescalero Apache boundary.

A. Designated uses: domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat, public water supply and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 600 µS/cm or less in Eagle creek, 1,100 µS/cm or less in Bonito creek and 1,500 µS/cm or less in the Rio Ruidoso; phosphorus (unfiltered sample) less than 0.1 mg/L; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.209 NMAC - Rp 20 NMAC 6.1.2209, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 7/10/2012; A, 4/23/2022]
[**NOTE:** The standards for Bonito lake are in 20.6.4.223 NMAC, effective 7/10/2012]

20.6.4.210 PECOS RIVER BASIN: Sumner reservoir.

A. Designated uses: irrigation storage, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.210 NMAC - Rp 20 NMAC 6.1.2210, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.211 PECOS RIVER BASIN: The main stem of the Pecos river from the headwaters of Sumner reservoir upstream to Tecolote creek excluding Santa Rosa reservoir.

A. Designated uses: fish culture, irrigation, marginal warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 3,000 mg/L or less, sulfate 2,000 mg/L or less and chloride 400 mg/L or less.

[20.6.4.211 NMAC - Rp 20 NMAC 6.1.2211, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 7/10/2012]
[**NOTE:** The standards for Santa Rosa reservoir are in 20.6.4.225 NMAC, effective 7/10/2012]

20.6.4.212 PECOS RIVER BASIN: Perennial tributaries to the main stem of the Pecos river from the headwaters of Sumner reservoir upstream to Santa Rosa dam.

A. Designated uses: irrigation, coldwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F) or less.

[20.6.4.212 NMAC - Rp 20 NMAC 6.1.2211.1, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.213 PECOS RIVER BASIN: McAllister lake.

A. Designated uses: coldwater aquatic life, secondary contact, livestock watering and wildlife habitat.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F) or less.

[20.6.4.213 NMAC - Rp 20 NMAC 6.1.2211.3, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.214 PECOS RIVER BASIN: Storrie lake.

A. Designated uses: coldwater aquatic life, warmwater aquatic life, primary contact, livestock watering, wildlife habitat, public water supply and irrigation storage.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.
[20.6.4.214 NMAC - Rp 20 NMAC 6.1.2211.5, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.215 PECOS RIVER BASIN: Perennial reaches of the Gallinas river upstream of the diversion for the Las Vegas municipal reservoir, perennial reaches of tributaries to the Gallinas river upstream of the diversion for the Las Vegas municipal reservoir, perennial reaches of Tecolote creek upstream of Blue creek and all perennial reaches of tributaries to Tecolote creek upstream of Blue creek.

A. **Designated uses:** domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat, industrial water supply and primary contact; and public water supply on the Gallinas river.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less (450 µS/cm or less in Wright Canyon creek); the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.
[20.6.4.215 NMAC - Rp 20 NMAC 6.1.2212, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 2/13/2018; A, 4/23/2022]
[**NOTE:** This segment was divided effective 2/13/2018. The standards for Tecolote creek from I-25 to Blue creek are under 20.6.4.230 NMAC.]

20.6.4.216 PECOS RIVER BASIN: The main stem of the Pecos river from Tecolote creek upstream to Cañon de Manzanita.

A. **Designated uses:** irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life and primary contact.

B. **Criteria:**

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 30°C (86°F) or less.

(2) At all flows above 10 cfs: TDS 250 mg/L or less, sulfate 25 mg/L or less and chloride 5 mg/L or less.
[20.6.4.216 NMAC - Rp 20 NMAC 6.1.2213, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.217 PECOS RIVER BASIN: Perennial reaches of Cow creek and all perennial reaches of its tributaries and the main stem of the Pecos river from Cañon de Manzanita upstream to its headwaters, including perennial reaches of all tributaries thereto except lakes identified in 20.6.4.222 NMAC.

A. **Designated uses:** domestic water supply, fish culture, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact; and public water supply on the main stem of the Pecos river.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.
[20.6.4.217 NMAC - Rp 20 NMAC 6.1.2214, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 7/10/2012]
[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for the additional segments are under 20.6.4.220 and 20.6.4.221 NMAC.]

20.6.4.218 PECOS RIVER BASIN: Lower Tansil lake and Lake Carlsbad.

A. **Designated uses:** industrial water supply, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 34°C (93.2°F) or less.
[20.6.4.218 NMAC - N, 5/23/2005; A, 12/1/2010]

20.6.4.219 PECOS RIVER BASIN: Avalon reservoir.

A. **Designated uses:** irrigation storage, livestock watering, wildlife habitat, secondary contact and warmwater aquatic life.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.
[20.6.4.219 NMAC - N, 5/23/2005; A, 12/1/2010]

20.6.4.220 PECOS RIVER BASIN: Perennial reaches of the Gallinas river and perennial reaches of tributaries to the Gallinas river from its mouth upstream to the diversion for the Las Vegas municipal reservoir, except Pecos Arroyo.

A. Designated uses: irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 30°C (86°F) or less.

[20.6.4.220 NMAC - N, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

20.6.4.221 PECOS RIVER BASIN: Pecos Arroyo.

A. Designated uses: livestock watering, wildlife habitat, warmwater aquatic life and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 206 cfu/100 mL, single sample 940 cfu/100 mL.

[20.6.4.221 NMAC - N, 5/23/2005; A, 12/1/2010]

20.6.4.222 PECOS RIVER BASIN: Johnson lake, Katherine lake, Lost Bear lake, Pecos Baldy lake, Spirit lake, Stewart lake and Truchas lakes (north and south).

A. Designated uses: high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.222 NMAC - N, 7/10/2012]

20.6.4.223 PECOS RIVER BASIN: Bonito lake.

A. Designated uses: high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering, wildlife habitat and public water supply.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: specific conductance 1100 µS/cm or less; phosphorus (unfiltered sample) less than 0.1 mg/L; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.223 NMAC - N, 7/10/2012]

20.6.4.224 PECOS RIVER BASIN: Monastery lake.

A. Designated uses: coolwater aquatic life, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of *E. coli* bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

[20.6.4.224 NMAC - N, 7/10/2012]

20.6.4.225 PECOS RIVER BASIN: Santa Rosa reservoir.

A. Designated uses: coolwater aquatic life, irrigation, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.225 NMAC - N, 7/10/2012]

20.6.4.226 PECOS RIVER BASIN: Perch lake.

A. Designated uses: coolwater aquatic life, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.226 NMAC - N, 7/10/2012]

20.6.4.227 PECOS RIVER BASIN: Lea lake.

A. Designated uses: warmwater aquatic life, primary contact and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.227 NMAC - N, 7/10/2012]

20.6.4.228 PECOS RIVER BASIN: Cottonwood lake and Devil's Inkwell.

A. Designated uses: coolwater aquatic life, primary contact and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of *E. coli* bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

[20.6.4.228 NMAC - N, 7/10/2012]

20.6.4.229 PECOS RIVER BASIN: Mirror lake.

A. Designated uses: warmwater aquatic life, primary contact and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of *E. coli* bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

[20.6.4.229 NMAC - N, 7/10/2012]

20.6.4.230 PECOS RIVER BASIN: Perennial reaches of Tecolote creek from I-25 to Blue creek.

A. Designated uses: domestic water supply, coolwater aquatic life, irrigation, livestock watering, wildlife habitat, and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.230 NMAC - N, 2/13/2018]

20.6.4.231 PECOS RIVER BASIN: The main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from state highway 24 near Dunken, perennial reaches of North Spring river and perennial reaches of the Rio Hondo downstream of Bonney canyon.

A. Designated uses: irrigation, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 14,000 mg/L or less, sulfate 3,000 mg/L or less and chloride 6,000 mg/L or less.

[20.6.4.231 NMAC - N, 4/23/2022]

20.6.4.232 - 20.6.4.300 [**RESERVED**]

20.6.4.301 CANADIAN RIVER BASIN: The main stem of the Canadian river from the New Mexico-Texas line upstream to Ute dam, and any flow that enters the main stem from Revuelto creek.

A. Designated uses: irrigation, marginal warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) TDS 6,500 mg/L or less at flows above 25 cfs.

[20.6.4.301 NMAC - Rp 20 NMAC 6.1.2301, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.302 CANADIAN RIVER BASIN: Ute reservoir.

A. **Designated uses:** livestock watering, wildlife habitat, public water supply, industrial water supply, primary contact and warmwater aquatic life.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.302 NMAC - Rp 20 NMAC 6.1.2302, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.303 CANADIAN RIVER BASIN: The main stem of the Canadian river from the headwaters of Ute reservoir upstream to Conchas dam, the perennial reaches of Pajarito and Ute creeks and their perennial tributaries.

A. **Designated uses:** irrigation, marginal warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.303 NMAC - Rp 20 NMAC 6.1.2303, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.304 CANADIAN RIVER BASIN: Conchas reservoir.

A. **Designated uses:** irrigation storage, livestock watering, wildlife habitat, public water supply, primary contact and warmwater aquatic life.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.304 NMAC - Rp 20 NMAC 6.1.2304, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.305 CANADIAN RIVER BASIN: The main stem of the Canadian river from the headwaters of Conchas reservoir upstream to the New Mexico-Colorado line, perennial reaches of the Conchas river, the Mora river downstream from the USGS gaging station near Shoemaker, the Vermejo river downstream from Rail canyon and perennial reaches of Raton, Chicorica (except Lake Maloya and Lake Alice) and Uña de Gato creeks.

A. **Designated uses:** irrigation, marginal warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. **Criteria:**

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) TDS 3,500 mg/L or less at flows above 10 cfs.

[20.6.4.305 NMAC - Rp 20 NMAC 6.1.2305, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017]

[**NOTE:** This segment was divided effective 12/1/2010. The standards for Lake Alice and Lake Maloya are under 20.6.4.311 and 20.6.4.312 NMAC, respectively.]

20.6.4.306 CANADIAN RIVER BASIN: The Cimarron river downstream from state highway 21 in Cimarron to the Canadian river and all perennial reaches of tributaries to the Cimarron river downstream from state highway 21 in Cimarron.

A. **Designated uses:** irrigation, warmwater aquatic life, livestock watering, wildlife habitat and primary contact; and public water supply on Cimarroncito creek.

B. **Criteria:**

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) TDS 3,500 mg/L or less at flows above 10 cfs.

[20.6.4.306 NMAC - Rp 20 NMAC 6.1.2305.1, 10/12/2000; A, 7/19/2001; A, 5/23/2005; A, 12/1/2010]

20.6.4.307 CANADIAN RIVER BASIN: Perennial reaches of the Mora river from the USGS gaging station near Shoemaker upstream to the state highway 434 bridge in Mora, all perennial reaches of tributaries to the Mora river downstream from the USGS gaging station at La Cueva in San Miguel and Mora counties except lakes identified in 20.6.4.313 NMAC, perennial reaches of Ocate creek downstream of Ocate, perennial reaches of tributaries to Ocate creek downstream of Ocate, and perennial reaches of Rayado creek downstream of Miami lake diversion in Colfax county.

A. **Designated uses:** marginal coldwater aquatic life, warmwater aquatic life, primary contact, irrigation, livestock watering and wildlife habitat.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.307 NMAC - Rp 20 NMAC 6.1.2305.3, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 7/10/2012; A, 4/23/2022]

20.6.4.308 CANADIAN RIVER BASIN: Charette lakes.

A. **Designated uses:** coldwater aquatic life, warmwater aquatic life, secondary contact, livestock watering and wildlife habitat.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.308 NMAC - Rp 20 NMAC 6.1.2305.5, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.309 CANADIAN RIVER BASIN: The Mora river and perennial reaches of its tributaries upstream from the state highway 434 bridge in Mora except lakes identified in 20.6.4.313 NMAC, all perennial reaches of tributaries to the Mora river upstream from the USGS gaging station at La Cueva, perennial reaches of Coyote creek, perennial reaches of tributaries to Coyote creek, the Cimarron river above state highway 21 in Cimarron, perennial reaches of tributaries to the Cimarron river above state highway 21 in Cimarron except Eagle Nest lake, all perennial reaches of tributaries to the Cimarron river north and northwest of highway 64 except north and south Shuree ponds, perennial reaches of Rayado creek above Miami lake diversion, perennial reaches of tributaries to Rayado creek above Miami lake diversion, Ocate creek and perennial reaches of its tributaries upstream of Ocate, perennial reaches of the Vermejo river upstream from Rail canyon and all other perennial reaches of tributaries to the Canadian river northwest and north of U.S. highway 64 in Colfax county unless included in other segments.

A. **Designated uses:** domestic water supply, irrigation, high quality coldwater aquatic life, livestock watering, wildlife habitat, and primary contact; and public water supply on the Cimarron river upstream from Cimarron, on perennial reaches of Rayado creek and on perennial reaches of tributaries to Rayado creek.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 500 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.309 NMAC - Rp 20 NMAC 6.1.2306, 10/12/2000; A, 7/19/2001; A, 5/23/2005; A, 12/1/2010; A, 7/10/2012; A, 4/23/2022]

[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for the additional segment are under 20.6.4.310 NMAC. The standards for Shuree ponds are in 20.6.4.314 NMAC and the standards for Eagle Nest lake are in 20.6.4.315 NMAC, effective 7/10/2012]

20.6.4.310 CANADIAN RIVER BASIN: Perennial reaches of Corrumpa creek.

A. **Designated uses:** livestock watering, wildlife habitat, irrigation, primary contact and coldwater aquatic life.

B. **Criteria:**

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: temperature 25°C (77°F) or less; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

(2) TDS 1,200 mg/L or less, sulfate 600 mg/L or less, chloride 40 mg/L or less.

[20.6.4.310 NMAC - N, 5/23/2005; A, 12/1/2010]

20.6.4.311 CANADIAN RIVER BASIN: Lake Alice.

A. **Designated uses:** marginal coldwater aquatic life, irrigation, livestock watering, wildlife habitat, primary contact and public water supply.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.311 NMAC - N, 12/1/2010; A, 4/23/2022]

20.6.4.312 CANADIAN RIVER BASIN: Lake Maloya.

A. Designated uses: coldwater aquatic life, irrigation, livestock watering, wildlife habitat, primary contact and public water supply.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.312 NMAC - N, 12/1/2010; A, 4/23/2022]

20.6.4.313 CANADIAN RIVER BASIN: Encantada lake, Maestas lake, Middle Fork lake of Rio de la Casa, North Fork lake of Rio de la Casa and Pacheco lake.

A. Designated uses: high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.313 NMAC - N, 7/10/2012]

20.6.4.314 CANADIAN RIVER BASIN: Shuree ponds (north and south).

A. Designated uses: high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: specific conductance 500 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.314 NMAC - N, 7/10/2012]

20.6.4.315 CANADIAN RIVER BASIN: Eagle Nest lake.

A. Designated uses: high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering, wildlife habitat and public water supply.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: specific conductance 500 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.315 NMAC - N, 7/10/2012]

20.6.4.316 CANADIAN RIVER BASIN: Clayton lake.

A. Designated uses: coolwater aquatic life, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of *E. coli* bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

[20.6.4.316 NMAC - N, 7/10/2012]

20.6.4.317 CANADIAN RIVER BASIN: Springer lake.

A. Designated uses: coolwater aquatic life, irrigation, primary contact, livestock watering, wildlife habitat, and public water supply.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.317 NMAC - N, 7/10/2012; A, 3/2/2017]

20.6.4.318 CANADIAN RIVER BASIN: Doggett creek.

A. Designated uses: Warm water aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: The use-specific criteria in 20.6.4.900 NMAC are applicable to the designated uses, except that the following site-specific criteria apply: the monthly geometric mean of E. coli bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

C. Discharger-specific temporary standard:

(1) Discharger: City of Raton wastewater treatment plant

(2) NPDES permit number: NM0020273, Outfall 001

(3) Receiving waterbody: Doggett creek, 20.6.4.318 NMAC

(4) Discharge latitude/longitude: 36° 52' 13.91" N / 104° 25' 39.18" W

(5) **Pollutant(s):** nutrients; total nitrogen and total phosphorus

(6) **Factor of issuance:** substantial and widespread economic and social impacts (40 CFR 131.10(g)(6))

(7) **Highest attainable condition:** interim effluent condition of 8.0 mg/L total nitrogen and 1.6 mg/L total phosphorus as 30-day averages. The highest attainable condition shall be either the highest attainable condition identified at the time of the adoption, or any higher attainable condition later identified during any reevaluation, whichever is more stringent (40 CFR 131.14(b)(1)(iii)).

(8) **Effective date of temporary standard:** This temporary standard becomes effective for Clean Water Act purposes on the date of EPA approval.

(9) **Expiration date of temporary standard:** no later than 20 years from the effective date.

(10) **Reevaluation period:** at each succeeding review of water quality standards and at least once every five years from the effective date of the temporary standard (Paragraph (8) of Subsection H of 20.6.4.10 NMAC, 40 CFR 131.14(b)(1)(v)). If the discharger cannot demonstrate that sufficient progress has been made the commission may revoke approval of the temporary standard or provide additional conditions to the approval of the temporary standard. If the reevaluation is not completed at the frequency specified or the Department does not submit the reevaluation to EPA within 30 days of completion, the underlying designated use and criterion will be the applicable water quality standard for Clean Water Act purposes until the Department completes and submits the reevaluation to EPA. Public input on the reevaluation will be invited during NPDES permit renewals or triennial reviews, as applicable, in accordance with the State's most current approved water quality management plan and continuing planning process.

(11) **Timeline for proposed actions.** Tasks and target completion dates are listed in the most recent, WQCC-approved version of the New Mexico Environment Department, Surface Water Quality Bureau's "Nutrient Temporary Standards for City of Raton Wastewater Treatment Plant, NPDES No. NM0020273 to Doggett Creek."

[20.6.4.318 NMAC - N, 05/22/2020; A, 4/23/2022]

20.6.4.319 - 20.6.4.400 [**RESERVED**]

20.6.4.401 SAN JUAN RIVER BASIN: The main stem of the San Juan river from the Navajo Nation boundary at the Hogback upstream to its confluence with the Animas river. Some waters in this segment are under the joint jurisdiction of the state and the Navajo Nation.

A. **Designated uses:** public water supply, industrial water supply, irrigation, livestock watering, wildlife habitat, primary contact, marginal coldwater aquatic life and warmwater aquatic life.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 32.2°C (90°F) or less.

[20.6.4.401 NMAC - Rp 20 NMAC 6.1.2401, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for the additional segment are under 20.6.4.408 NMAC.]

20.6.4.402 SAN JUAN RIVER BASIN: La Plata river from its confluence with the San Juan river upstream to the New Mexico-Colorado line.

A. **Designated uses:** irrigation, marginal warmwater aquatic life, marginal coldwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 32.2°C (90°F) or less.

[20.6.4.402 NMAC - Rp 20 NMAC 6.1.2402, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.403 SAN JUAN RIVER BASIN: The Animas river from its confluence with the San Juan river upstream to Estes arroyo.

A. **Designated uses:** Public water supply, industrial water supply, irrigation, livestock watering, wildlife habitat, coolwater aquatic life, and primary contact.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 29°C (84.2°F) or less.

[20.6.4.403 NMAC - Rp 20 NMAC 6.1.2403, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017]

20.6.4.404 SAN JUAN RIVER BASIN: The Animas river from Estes arroyo upstream to the Southern Ute Indian tribal boundary.

A. Designated uses: Coolwater aquatic life, irrigation, livestock watering, wildlife habitat, public water supply, industrial water supply and primary contact.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: phosphorus (unfiltered sample) 0.l mg/L or less.

[20.6.4.404 NMAC - Rp 20 NMAC 6.1.2404, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017]

20.6.4.405 SAN JUAN RIVER BASIN: The main stem of the San Juan river from Cañon Largo upstream to the Navajo dam.

A. Designated uses: high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat, public water supply, industrial water supply and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 400 µS/cm or less; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.405 NMAC - Rp 20 NMAC 6.1.2405, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

20.6.4.406 SAN JUAN RIVER BASIN: Navajo reservoir in New Mexico.

A. Designated uses: coldwater aquatic life, warmwater aquatic life, irrigation storage, livestock watering, wildlife habitat, public water supply, industrial water supply and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: phosphorus (unfiltered sample) 0.1 mg/L or less; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.406 NMAC - Rp 20 NMAC 6.1.2406, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.407 SAN JUAN RIVER BASIN: Perennial reaches of the Navajo river from the Jicarilla Apache reservation boundary to the Colorado border and perennial reaches of Los Pinos river in New Mexico.

A. Designated uses: coldwater aquatic life, irrigation, livestock watering, public water supply, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: phosphorus (unfiltered sample) 0.1 mg/L or less; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.407 NMAC - Rp 20 NMAC 6.1.2407, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.408 SAN JUAN RIVER BASIN: The main stem of the San Juan river from its confluence with the Animas river upstream to its confluence with Cañon Largo.

A. Designated uses: public water supply, industrial water supply, irrigation, livestock watering, wildlife habitat, primary contact, marginal coldwater aquatic life and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 32.2°C (90°F) or less.

[20.6.4.408 NMAC - N, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

20.6.4.409 SAN JUAN RIVER BASIN: Lake Farmington.

A. Designated uses: public water supply, wildlife habitat, livestock watering, primary contact, coldwater aquatic life and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F) or less.

[20.6.4.409 NMAC - N, 12/1/2010]

20.6.4.410 SAN JUAN RIVER BASIN: Jackson lake.

A. Designated uses: coolwater aquatic life, irrigation, primary contact, livestock watering and wildlife habitat.

B. **Criteria:** The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of *E. coli* bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.
[20.6.4.410 NMAC - N, 7/10/2012]

20.6.4.411 - 20.6.4.450: [**RESERVED**]

20.6.4.451 LITTLE COLORADO RIVER BASIN: The Rio Nutria upstream of the Zuni pueblo boundary, Tampico draw, Agua Remora, Tampico springs.

A. **Designated uses:** coolwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.
[20.6.4.451 NMAC - N, 12/1/2010]

20.6.4.452 LITTLE COLORADO RIVER BASIN: Ramah lake.

A. **Designated uses:** coldwater aquatic life, warmwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F) or less.
[20.6.4.452 NMAC - N, 12/1/2010]

20.6.4.453 LITTLE COLORADO RIVER BASIN: Quemado lake.

A. **Designated uses:** coolwater aquatic life, primary contact, livestock watering and wildlife habitat.

B. **Criteria:** The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.
[20.6.4.453 NMAC - N, 7/10/2012]

20.6.4.454 - 20.6.4.500 [**RESERVED**]

20.6.4.501 GILA RIVER BASIN: The main stem of the Gila river from the New Mexico-Arizona line upstream to Redrock canyon and perennial reaches of streams in Hidalgo county.

A. **Designated uses:** irrigation, marginal warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.
[20.6.4.501 NMAC - Rp 20 NMAC 6.1.2501, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.502 GILA RIVER BASIN: The main stem of the Gila river from Redrock canyon upstream to the confluence of the West Fork Gila river and East Fork Gila river and perennial reaches of tributaries to the Gila river downstream of Mogollon creek.

A. **Designated uses:** industrial water supply, irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life, primary contact and warmwater aquatic life.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: 28°C (82.4°F) or less.
[20.6.4.502 NMAC - Rp 20 NMAC 6.1.2502, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017]

20.6.4.503 GILA RIVER BASIN: All perennial tributaries to the Gila river upstream of and including Mogollon creek.

A. **Designated uses:** domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance of 400 µS/cm or less for all perennial tributaries except West Fork Gila and tributaries thereto, specific conductance of 300 µS/cm or less; 32.2°C (90°F) or less in the east fork of the Gila river and Sapillo creek downstream of Lake Roberts; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.
[20.6.4.503 NMAC - Rp 20 NMAC 6.1.2503, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017]

20.6.4.504 GILA RIVER BASIN: Wall lake, Lake Roberts and Snow lake.

A. Designated uses: coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: specific conductance 300 µS/cm or less.

[20.6.4.504 NMAC - Rp 20 NMAC 6.1.2504, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for the additional segment are under 20.6.4.806 NMAC.]

20.6.4.505 GILA RIVER BASIN: Bill Evans lake.

A. Designated uses: coolwater aquatic life, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.505 NMAC - N, 7/10/2012]

20.6.4.506 - 20.6.4.600 [**RESERVED**]

20.6.4.601 SAN FRANCISCO RIVER BASIN: The main stem of the San Francisco river from the New Mexico-Arizona line upstream to state highway 12 at Reserve and perennial reaches of Mule creek.

A. Designated uses: irrigation, marginal warmwater and marginal coldwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.601 NMAC - Rp 20 NMAC 6.1.2601, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.602 SAN FRANCISCO RIVER BASIN: The main stem of the San Francisco river from state highway 12 at Reserve upstream to the New Mexico-Arizona line.

A. Designated uses: coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F) or less.

[20.6.4.602 NMAC - Rp 20 NMAC 6.1.2602, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.603 SAN FRANCISCO RIVER BASIN: All perennial reaches of tributaries to the San Francisco river above the confluence of Whitewater creek and including Whitewater creek.

A. Designated uses: domestic water supply, fish culture, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 400 µS/cm or less; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less; and temperature 25°C (77°F) or less in Tularosa creek.

[20.6.4.603 NMAC - Rp 20 NMAC 6.1.2603, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.604 - 20.6.4.700 [**RESERVED**]

20.6.4.701 DRY CIMARRON RIVER: Perennial portions of the Dry Cimarron river above Oak creek and perennial reaches of Oak creek.

A. Designated uses: coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: temperature 25°C (77°F) or less, the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

(2) TDS 1,200 mg/L or less, sulfate 600 mg/L or less and chloride 40 mg/L or less.

[20.6.4.701 NMAC - Rp 20 NMAC 6.1.2701, 10/12/2000; A, 5/23/2005 A, 12/1/2010]
[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for the additional segment are under 20.6.4.702 NMAC.]

20.6.4.702 DRY CIMARRON RIVER: Perennial portions of the Dry Cimarron river below Oak creek, and perennial portions of Long canyon and Carrizozo creeks.

A. Designated uses: coolwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

(2) TDS 1,200 mg/L or less, sulfate 600 mg/L or less and chloride 40 mg/L or less.

[20.6.4.702 NMAC - N, 5/23/2005; A, 12/1/2010; A, 7/10/2012]

20.6.4.703 - 20.6.4.800 [**RESERVED**]

20.6.4.801 CLOSED BASINS: Rio Tularosa upstream of the old U.S. highway 70 bridge crossing east of Tularosa and all perennial tributaries to the Tularosa basin except Three Rivers and Dog Canyon creek, and excluding waters on the Mescalero tribal lands.

A. Designated uses: coldwater aquatic life, irrigation, livestock watering, wildlife habitat, public water supply and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.801 NMAC - Rp 20 NMAC 6.1.2801, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 2/13/2018]
[**NOTE:** This segment was divided effective 2/13/2018. The standards for Dog Canyon creek are under 20.6.4.810 NMAC.]

20.6.4.802 CLOSED BASINS: Perennial reaches of Three Rivers.

A. Designated uses: irrigation, domestic water supply, high quality coldwater aquatic life, primary contact, livestock watering and wildlife habitat.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 500 µS/cm or less; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.802 NMAC - Rp 20 NMAC 6.1.2802, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.803 CLOSED BASINS: Perennial reaches of the Mimbres river downstream of the confluence with Allie canyon and all perennial reaches of tributaries thereto.

A. Designated uses: Coolwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less and temperature of 30°C (86°F) or less.

[20.6.4.803 NMAC - Rp 20 NMAC 6.1.2803, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017]

20.6.4.804 CLOSED BASINS: Perennial reaches of the Mimbres river upstream of the confluence with Allie canyon to Cooney canyon, and all perennial reaches of East Fork Mimbres (McKnight canyon) downstream of the fish barrier, and all perennial reaches thereto.

A. Designated uses: Irrigation, domestic water supply, coldwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.804 NMAC - Rp 20 NMAC 6.1.2804, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 2/28/2018; A, 3/2/2017]

[**NOTE:** The segment covered by this section was divided effective 3/2/2017. The standards for the additional segment are covered under 20.6.4.807 NMAC.]

20.6.4.805 CLOSED BASINS: Perennial reaches of the Sacramento river (Sacramento-Salt Flat closed basin) and all perennial tributaries thereto.

A. Designated uses: domestic water supply, livestock watering, wildlife habitat, marginal coldwater aquatic life and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.805 NMAC - Rp 20 NMAC 6.1.2805, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.806 CLOSED BASINS: Bear canyon reservoir.

A. Designated uses: coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: specific conductance 300 µS/cm or less.

[20.6.4.806 NMAC - N, 5/23/2005; A, 12/1/2010]

20.6.4.807 CLOSED BASINS: Perennial reaches of the Mimbres river upstream of Cooney canyon and all perennial reaches thereto, including perennial reaches of East Fork Mimbres river (McKnight canyon) upstream of the fish barrier.

A. Designated uses: Irrigation, domestic water supply, high quality coldwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.807 NMAC - N, 3/2/2017]

20.6.4.808 CLOSED BASINS: Perennial and intermittent watercourses within Smelter Tailing Soils Investigation Unit lands at the Chino mines company, excluding those ephemeral waters listed in 20.6.4.809 NMAC and including, but not limited to the mainstem of Lampbright draw, beginning at the confluence of Lampbright Draw with Rustler canyon, all tributaries that originate west of Lampbright draw to the intersection of Lampbright draw with U.S. 180, and all tributaries of Whitewater creek that originate east of Whitewater creek from the confluence of Whitewater creek with Bayard canyon downstream to the intersection of Whitewater creek with U.S. 180.

A. Designated uses: Warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the acute and chronic aquatic life criteria for copper set forth in Subsection I of 20.6.4.900 NMAC shall be determined by multiplying that criteria by the water effect ratio ("WER") adjustment expressed by the following equation:

$$\mathrm{WER} = \frac{\left[10^{0.588+(0.703 \times \log \mathrm{DOC})+(0.395 \times \log \mathrm{Alkalinity})}\right] \times \left(\frac{100}{\mathrm{Hardness}}\right)^{0.9422}}{19.31}$$

For purposes of this section, dissolved organic carbon (DOC) is expressed in units of milligrams carbon per liter or mg C/L; alkalinity is expressed in units of mg/L as $CaCO_3$, and hardness is expressed in units of mg/L as $CaCO_3$. In waters that contain alkalinity concentrations greater than 250 mg/L, a value of 250 mg/L shall be used in the equation. In waters that contain DOC concentrations greater than 16 mg C/L, a value of 16 mg C/L shall be used in the equation. In waters that contain hardness concentrations greater than 400 mg/L, a value of 400 mg/L shall be used in the equation. The alkalinity, hardness and DOC concentrations used to calculate the WER value are those measured in the subject water sample.

[20.6.4.808 NMAC - N, 3/2/2017]

20.6.4.809 CLOSED BASINS: Ephemeral watercourses within smelter tailing soils investigation unit lands at the Chino mines company, limited to Chino mines property subwatershed drainage A and tributaries

thereof, Chino mines property subwatershed drainage B and tributaries thereof (excluding the northwest tributary containing Ash spring and the Chiricahua leopard frog critical habitat transect); Chino mines property subwatershed drainage C and tributaries thereof (excluding reaches containing Bolton spring, the Chiricahua leopard frog critical habitat transect and all reaches in subwatershed C that are upstream of the Chiricahua leopard frog critical habitat); subwatershed drainage D and tributaries thereof (drainages D-1, D-2 and D-3, excluding the southeast tributary in drainage D1 that contains Brown spring) and subwatershed drainage E and all tributaries thereof (drainages E-1, E-2 and E-3).

A. **Designated uses:** Limited aquatic life, livestock watering, wildlife habitat and secondary contact.

B. **Criteria:** The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the acute aquatic life criteria for copper set forth in Subsection I of 20.6.4.900 NMAC shall be determined by multiplying that criteria by the water effect ratio (“WER”) adjustment expressed by the following equation:

$$WER = \frac{[10^{0.588+(0.703 \times \log DOC)+(0.395 \times \log Alkalinity)}] \times (\frac{100}{Hardness})^{0.9422}}{19.31}$$

For purposes of this section, dissolved organic carbon (DOC) is expressed in units of milligrams carbon per liter or mg C/L; alkalinity is expressed in units of mg/L as $CaCO_3$, and hardness is expressed in units of mg/L as $CaCO_3$. In waters that contain alkalinity concentrations greater than 250 mg/L, a value of 250 mg/L shall be used in the equation. In waters that contain DOC concentrations greater than 16 mg C/L, a value of 16 mg C/L shall be used in the equation. In waters that contain hardness concentrations greater than 400 mg/L, a value of 400 mg/L shall be used in the equation. The alkalinity, hardness and DOC concentrations used to calculate the WER value are those measured in the subject water sample.

[20.6.4.809 NMAC - N, 3/2/2017]

20.6.4.810 CLOSED BASINS: Perennial reaches of Dog Canyon creek.

A. **Designated uses:** coolwater aquatic life, irrigation, livestock watering, wildlife habitat, public water supply, and primary contact.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.810 NMAC - N, 2/13/2018]

20.6.4.811 - 20.6.4.899 [**RESERVED**]

20.6.4.900 CRITERIA APPLICABLE TO EXISTING, DESIGNATED OR ATTAINABLE USES UNLESS OTHERWISE SPECIFIED IN 20.6.4.97 THROUGH 20.6.4.899 NMAC:

A. **Fish culture and water supply:** Fish culture, public water supply and industrial water supply are designated uses in particular classified waters of the state where these uses are actually being realized. However, no numeric criteria apply uniquely to these uses. Water quality adequate for these uses is ensured by the general criteria and numeric criteria for bacterial quality, pH and temperature.

B. **Domestic water supply:** Surface waters of the state designated for use as domestic water supplies shall not contain substances in concentrations that create a lifetime cancer risk of more than one cancer per 100,000 exposed persons. Those criteria listed under domestic water supply in Subsection J of this section apply to this use.

C. **Irrigation and irrigation storage:** the following numeric criteria and those criteria listed under irrigation in Subsection J of this section apply to this use:

(1) dissolved selenium 0.13 mg/L

(2) dissolved selenium in presence of >500 mg/L SO_4 0.25 mg/L.

D. **Primary contact:** The monthly geometric mean of E. coli bacteria of 126 cfu/100 mL or MPN/100 ml, a single sample of E. coli bacteria of 410 cfu/100 mL or MPN/100 mL, a single sample of total microcystins of 8 µg/L with no more than three exceedances within a 12-month period and a single sample of cylindrospermopsin of 15 µg/L with no more than three exceedances within a 12-month period, and pH within the range of 6.6 to 9.0 apply to this use. The results for *E. coli* may be reported as either colony forming units (CFU) or the most probable number (MPN) depending on the analytical method used.

E. **Secondary contact:** The monthly geometric mean of E. coli bacteria of 548 cfu/100 mL or MPN/100 mL and single sample of 2507 cfu/100 mL or MPN/100 mL apply to this use. The results for *E. coli* may be reported as either colony forming units (CFU) or the most probable number (MPN), depending on the analytical method used.

F. Livestock watering: the criteria listed in Subsection J of this section for livestock watering apply to this use.

G. Wildlife habitat: Wildlife habitat shall be free from any substances at concentrations that are toxic to or will adversely affect plants and animals that use these environments for feeding, drinking, habitat or propagation; can bioaccumulate; or might impair the community of animals in a watershed or the ecological integrity of surface waters of the state. The numeric criteria listed in Subsection J for wildlife habitat apply to this use.

H. Aquatic life: Surface waters of the state with a designated, existing or attainable use of aquatic life shall be free from any substances at concentrations that can impair the community of plants and animals in or the ecological integrity of surface waters of the state. Except as provided in Paragraph (7) of this subsection, the acute and chronic aquatic life criteria set out in Subsections I, J, K and L of this section and the human health-organism only criteria set out in Subsection J of this section are applicable to all aquatic life use subcategories. In addition, the specific criteria for aquatic life subcategories in the following paragraphs apply to waters classified under the respective designations.

(1) High quality coldwater: dissolved oxygen 6.0 mg/L or more, 4T3 temperature 20°C (68°F), maximum temperature 23°C (73°F), pH within the range of 6.6 to 8.8 and specific conductance a segment-specific limit between 300 µS/cm and 1,500 µS/cm depending on the natural background in the particular surface water of the state (the intent of this criterion is to prevent excessive increases in dissolved solids which would result in changes in community structure). Where a single segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature and no 4T3 temperature applies.

(2) Coldwater: dissolved oxygen 6.0 mg/L or more, 6T3 temperature 20°C (68°F), maximum temperature 24°C (75°F) and pH within the range of 6.6 to 8.8. Where a single segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature and no 6T3 temperature applies.

(3) Marginal coldwater: dissolved oxygen 6 mg/L or more, 6T3 temperature 25°C (77°F), maximum temperature 29°C (84°F) and pH within the range from 6.6 to 9.0. Where a single segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature and no 6T3 temperature applies.

(4) Coolwater: dissolved oxygen 5.0 mg/L or more, maximum temperature 29°C (84°F) and pH within the range of 6.6 to 9.0.

(5) Warmwater: dissolved oxygen 5 mg/L or more, maximum temperature 32.2°C (90°F) and pH within the range of 6.6 to 9.0. Where a segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature.

(6) Marginal warmwater: dissolved oxygen 5 mg/L or more, pH within the range of 6.6 to 9.0 and temperatures that may routinely exceed 32.2°C (90°F). Where a segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature.

(7) Limited aquatic life: The acute aquatic life criteria of Subsections I and J of this section apply to this subcategory. Chronic aquatic life criteria do not apply unless adopted on a segment-specific basis. Human health-organism only criteria apply only for persistent toxic pollutants unless adopted on a segment-specific basis.

I. Hardness-dependent acute and chronic aquatic life criteria for metals are calculated using the following equations excluding copper (Cu) criteria for the Pajarito plateau surface waters as described in paragraph 4 of this subsection. The criteria are expressed as a function of hardness (as mg $CaCO_3$/L). With the exception of aluminum, the equations are valid only for hardness concentrations of 0-400 mg/L. For hardness concentrations above 400 mg/L, the criteria for 400 mg/L apply. For aluminum the equations are valid only for hardness concentrations of 0-220 mg/L. For hardness concentrations above 220 mg/L, the aluminum criteria for 220 mg/L apply. Calculated criteria must adhere to the treatment of significant figures and rounding identified in *Standard Methods For The Examination Of Water And Wastewater*, latest edition, American public health association.

(1) Acute aquatic life criteria for metals: The equation to calculate acute criteria in µg/L is $\exp(m_A[\ln(\text{hardness})] + b_A)(CF)$. Except for aluminum, the criteria are based on analysis of dissolved metal. For aluminum, the criteria are based on analysis of total recoverable aluminum in a sample that has a pH between 6.5 and 9.0 and is filtered to minimize mineral phases as specified by the department. The equation parameters are as follows:

Metal	**m_A**	**b_A**	**Conversion factor (CF)**

Aluminum (Al)	1.3695	1.8308	
Cadmium (Cd)	0.9789	-3.866	1.136672-[(ln hardness)(0.041838)]
Chromium (Cr) III	0.8190	3.7256	0.316
Copper (Cu)	0.9422	-1.700	0.960
Lead (Pb)	1.273	-1.460	1.46203-[(ln hardness)(0.145712)]
Manganese (Mn)	0.3331	6.4676	
Nickel (Ni)	0.8460	2.255	0.998
Silver (Ag)	1.72	-6.59	0.85
Zinc (Zn)	0.9094	0.9095	0.978

(2) **Chronic aquatic life criteria for metals:** The equation to calculate chronic criteria in µg/L is $\exp(m_C[\ln(\text{hardness})] + b_C)(CF)$. Except for aluminum, the criteria are based on analysis of dissolved metal. For aluminum, the criteria are based on analysis of total recoverable aluminum in a sample that has a pH between 6.5 and 9.0 and is filtered to minimize mineral phases as specified by the department. The equation parameters are as follows:

Metal	**m_C**	**b_C**	**Conversion factor (CF)**
Aluminum (Al)	1.3695	0.9161	
Cadmium (Cd)	0.7977	-3.909	1.101672-[(ln hardness)(0.041838)]
Chromium (Cr) III	0.8190	0.6848	0.860
Copper (Cu)	0.8545	-1.702	0.960
Lead (Pb)	1.273	-4.705	1.46203-[(ln hardness)(0.145712)]
Manganese (Mn)	0.3331	5.8743	
Nickel (Ni)	0.8460	0.0584	0.997
Zinc (Zn)	0.9094	0.6235	0.986

(3) Selected values of calculated acute and chronic criteria (µg/L).

Hardness as $CaCO_3$, dissolved (mg/L)		**Al**	**Cd**	**Cr III**	**Cu**	**Pb**	**Mn**	**Ni**	**Ag**	**Zn**
25.0	Acute	512	0.490	183	3.64	13.9	1,880	145	0.30	45.4
	Chronic	205	0.253	23.8	2.74	0.541	1,040	16.1		34.4
30.0	Acute	658	0.581	212	4.32	17.0	2,000	169	0.40	53.5
	Chronic	263	0.290	27.6	3.20	0.664	1,100	18.8		40.5
40.0	Acute	975	0.761	269	5.67	23.5	2,200	216	0.66	69.5
	Chronic	391	0.360	35.0	4.09	0.916	1,220	24.0		52.7
50.0	Acute	1,320	0.938	323	6.99	30.1	2,370	260	0.98	85.2
	Chronic	530	0.426	42.0	4.95	1.17	1,310	28.9		64.5
60.0	Acute	1,700	1.11	375	8.30	36.9	2,520	304	1.3	100
	Chronic	681	0.489	48.8	5.79	1.44	1,390	33.8		76.2
70.0	Acute	2,100	1.28	425	9.60	43.7	2,650	346	1.7	116
	Chronic	841	0.549	55.3	6.60	1.70	1,460	38.5		87.6
80.0	Acute	2,520	1.46	474	10.9	50.6	2,770	388	2.2	131
	Chronic	1,010	0.607	61.7	7.40	1.97	1,530	43.0		98.9
90.0	Acute	2,960	1.62	523	12.2	57.6	2,880	428	2.7	145
	Chronic	1,190	0.664	68.0	8.18	2.24	1,590	47.6		110
100	Acute	3,420	1.79	570	13.4	64.6	2,980	468	3.2	160
	Chronic	1,370	0.718	74.1	8.96	2.52	1,650	52.0		121
200	Acute	8,840	3.43	1,000	25.8	136	3,760	842	10	300
	Chronic	3,540	1.21	131	16.2	5.30	2,080	93.5		228

Hardness as $CaCO_3$, dissolved (mg/L)		Al	Cd	Cr III	Cu	Pb	Mn	Ni	Ag	Zn
220	Acute	10,100	3.74	1,090	28.2	151	3,880	912	12	328
	Chronic	4,030	1.30	141	17.6	5.87	2,140	101		248
300	Acute		5.00	1,400	37.8	208	4,300	1,190	21	434
	Chronic		1.64	182	22.9	8.13	2,380	132		329
400 and above	Acute		6.54	1,770	49.6	281	4,740	1,510	35	564
	Chronic		2.03	231	29.3	10.9	2,620	168		428

(4) Copper criteria for Pajarito plateau surface waters: from Guaje canyon in the north to the Rito de los Frijoles watershed in the south, from their headwaters to their confluence with the Rio Grande and all tributaries and streams thereto is as follows. For purposes of this Section, dissolved organic carbon (DOC) is in units of milligrams carbon per liter (mg C/L); and hardness is expressed in units of mg/L as $CaCO_3$. In waters that contain DOC concentrations greater than 29.7 mg/L, a value of 29.7 mg/L shall be used in the equation. In waters that contain hardness concentrations greater than 207 mg/L, a value of 207 mg/L shall be used in the following equations.

(a) Acute aquatic life criteria: The equation to calculate acute criteria in µg/L is $\exp(-22.914+1.017\times\ln(DOC)+0.045\times\ln(hardness)+5.176\times pH-0.261\times pH^2)$.

(b) Chronic aquatic life criteria: The equation to calculate chronic criteria in µg/L is $\exp(-23.391+1.017\times\ln(DOC)+0.045\times\ln(hardness)+5.176\times pH-0.261\times pH^2)$.

J. Use-specific numeric criteria.

(1) Table of numeric criteria: The following table sets forth the numeric criteria applicable to existing, designated and attainable uses. For metals, criteria represent the total sample fraction unless otherwise specified in the table. Additional criteria that are not compatible with this table are found in Subsections A through I, K~~, and~~ L, and M of this section.

Pollutant	CAS Number	DWS	Irr/Irr storage	LW	WH	Aquatic Life			Type
						Acute	Chronic	HH-OO	
Aluminum, dissolved	7429-90-5		5,000			750 i	87 i		
Aluminum, total recoverable	7429-90-5					a	a		
Antimony, dissolved	7440-36-0	6						640	P
Arsenic, dissolved	7440-38-2	10	100	200		340	150	9.0	C,P
Asbestos	1332-21-4	7,000,000 fibers/L							
Barium, dissolved	7440-39-3	2,000							
Beryllium, dissolved	7440-41-7	4							
Boron, dissolved	7440-42-8		750	5,000					
Cadmium, dissolved	7440-43-9	5	10	50		a	a		
Chloride	1688-70-06					860,000	230,000		
Chlorine residual	7782-50-5				11	19	11		
Chromium III, dissolved	16065-83-1					a	a		
Chromium VI, dissolved	18540-29-9					16	11		
Chromium, dissolved	7440-47-3	100	100	1,000					
Cobalt, dissolved	7440-48-4		50	1,000					
Copper, dissolved	7440-50-8	1300	200	500		a	a		
Cyanide, total recoverable	57-12-5	200			5.2	22.0	5.2	400	
Iron	7439-89-6						1,000		

Pollutant	CAS Number	DWS	Irr/Irr storage	LW	WH	Aquatic Life			Type
						Acute	Chronic	HH-OO	
Lead, dissolved	7439-92-1	15	5,000	100		a	a		
Manganese, dissolved	7439-96-5					a	a		
Mercury	7439-97-6	2		10	0.77				
Mercury, dissolved	7439-97-6					1.4	0.77		
Methylmercury	22967-92-6							0.3 mg/kg in fish tissue	P
Molybdenum, dissolved	7439-98-7		1,000						
Molybdenum, total recoverable	7439-98-7					7,920	1,895		
Nickel, dissolved	7440-02-0	700				a	a	4,600	P
Nitrate as N		10 mg/L							
Nitrite + Nitrate				132 mg/L					
Selenium, dissolved	7782-49-2	50	b	50				4,200	P
Selenium, total recoverable	7782-49-2				5.0	20.0	5.0		
Silver, dissolved	7440-22-4					a			
Thallium, dissolved	7440-28-0	2						0.47	P
Uranium, dissolved	7440-61-1	30							
Vanadium, dissolved	7440-62-2		100	100					
Zinc, dissolved	7440-66-6	10,500	2,000	25,000		a	a	26,000	P
Adjusted gross alpha		15 pCi/L		15 pCi/L					
Radium 226 + Radium 228		5 pCi/L		30.0 pCi/L					
Strontium 90		8 pCi/L							
Tritium		20,000 pCi/L		20,000 pCi/L					
Acenaphthene	83-32-9	2,100						90	
Acrolein	107-02-8	18				3.0	3.0	400	
Acrylonitrile	107-13-1	0.65						70	C
Aldrin	309-00-2	0.021				3.0		0.0000077	C,P
Anthracene	120-12-7	10,500						400	
Benzene	71-43-2	5						160	C
Benzidine	92-87-5	0.0015						0.11	C
Benzo(a)anthracene	56-55-3	0.048						0.013	C
Benzo(a)pyrene	50-32-8	0.2						0.0013	C,P
Benzo(b)fluoranthene	205-99-2	0.048						0.013	C
Benzo(k)fluoranthene	207-08-9	0.048						0.13	C
alpha-BHC	319-84-6	0.056						0.0039	C
beta-BHC	319-85-7	0.091						0.14	C
gamma-BHC (Lindane)	58-89-9	0.20				0.95		4.4	
Bis(2-chloroethyl) ether	111-44-4	0.30						22	C
Bis(2-chloro-1-methylethyl) ether	108-60-1	1,400						4,000	
Bis(2-ethylhexyl) phthalate	117-81-7	6						3.7	C
Bis(chloromethyl) ether	542-88-1							0.17	C
Bromoform	75-25-2	44						1,200	C
Butylbenzyl phthalate	85-68-7	7,000						1	C

Pollutant	CAS Number	DWS	Irr/Irr storage	LW	WH	Aquatic Life			Type
						Acute	Chronic	HH-OO	
Carbaryl	63-25-2					2.1	2.1		
Carbon tetrachloride	56-23-5	5						50	C
Chlordane	57-74-9	2				2.4	0.0043	0.0032	C,P
Chlorobenzene	108-90-7	100						800	
Chlorodibromomethane	124-48-1	4.2						210	C
Chloroform	67-66-3	57						2,000	
Chlorpyrifos	2921-88-2					0.083	0.041		
2-Chloronaphthalene	91-58-7	2,800						1,000	
2-Chlorophenol	95-57-8	175						800	
Chrysene	218-01-9	0.048						1.3	C
Demeton	8065-48-3						0.1		
Diazinon	333-41-5					0.17	0.17		
2,4-Dichlorophenoxyacetic acid	94-75-7							12,000	
Dichlorodiphenyldichloroethane (DDD)	72-54-8							0.0012	C
Dichlorodiphenyldichloroethylene (DDE)	72-55-9							0.00018	C
Dichlorodiphenyltrichloroethane (DDT)	50-29-3							0.0003	C,P
4,4'-DDT and derivatives		1.0			0.001	1.1	0.001		
Dibenzo(a,h)anthracene	53-70-3	0.048						0.0013	C
Dibutyl phthalate	84-74-2	3,500						30	
1,2-Dichlorobenzene	95-50-1	600						3,000	
1,3-Dichlorobenzene	541-73-1	469						10	
1,4-Dichlorobenzene	106-46-7	75						900	
3,3'-Dichlorobenzidine	91-94-1	0.78						1.5	C
Dichlorobromomethane	75-27-4	5.6						270	C
1,2-Dichloroethane	107-06-2	5						6,500	C
1,1-Dichloroethylene	75-35-4	7						20,000	
2,4-Dichlorophenol	120-83-2	105						60	
1,2-Dichloropropane	78-87-5	5.0						310	C
1,3-Dichloropropene	542-75-6	3.5						120	C
Dieldrin	60-57-1	0.022				0.24	0.056	0.000012	C,P
Diethyl phthalate	84-66-2	28,000						600	
Dimethyl phthalate	131-11-3	350,000						2,000	
2,4-Dimethylphenol	105-67-9	700						3,000	
Dinitrophenols	25550-58-7							1,000	
2,4-Dinitrophenol	51-28-5	70						300	
2,4-Dinitrotoluene	121-14-2	1.1						17	C
Dioxin	1746-01-6	3.0E-05						5.1E-08	C,P
1,2-Diphenylhydrazine	122-66-7	0.44						2.0	C
alpha-Endosulfan	959-98-8	62				0.22	0.056	30	
beta-Endosulfan	33213-65-9	62				0.22	0.056	40	
Endosulfan sulfate	1031-07-8	62						40	
Endrin	72-20-8	2				0.086	0.036	0.03	
Endrin aldehyde	7421-93-4	10.5						1	
Ethylbenzene	100-41-4	700						130	
Fluoranthene	206-44-0	1,400						20	

Pollutant	CAS Number	DWS	Irr/Irr storage	LW	WH	Aquatic Life			Type
						Acute	Chronic	HH-OO	
Fluorene	86-73-7	1,400						70	
Guthion	86-50-0						0.01		
Heptachlor	76-44-8	0.40				0.52	0.0038	0.000059	C
Heptachlor epoxide	1024-57-3	0.20				0.52	0.0038	0.00032	C
Hexachlorobenzene	118-74-1	1						0.00079	C,P
Hexachlorobutadiene	87-68-3	4.5						0.1	C
Hexachlorocyclohexane (HCH)-Technical	608-73-1							0.1	C
Hexachlorocyclopen-tadiene	77-47-4	50						4	
Hexachloroethane	67-72-1	25						1	C
Ideno(1,2,3-cd)pyrene	193-39-5	0.048						0.013	C
Isophorone	78-59-1	368						18,000	C
Malathion	121-75-5						0.1		
Methoxychlor	72-43-5						0.03	0.02	
Methyl bromide	74-83-9	49						10,000	
3-Methyl-4-chlorophenol	59-50-7							2,000	
2-Methyl-4,6-dinitrophenol	534-52-1	14						30	
Methylene chloride	75-09-2	5						10,000	C
Mirex	2385-85-5						0.001		
Nitrobenzene	98-95-3	18						600	
Nitrosamines	Various							12.4	C
Nitrosodibutylamine	924-16-3							2.2	C
Nitrosodiethylamine	55-18-5							12.4	C
N-Nitrosodimethylamine	62-75-9	0.0069						30	C
N-Nitrosodi-n-propylamine	621-64-7	0.050						5.1	C
N-Nitrosodiphenylamine	86-30-6	71						60	C
N-Nitrosopyrrolidine	930-55-2							340	C
Nonylphenol	84852-15-3					28	6.6		
Parathion	56-38-2					0.065	0.013		
Pentachlorobenzene	608-93-5							0.1	
Pentachlorophenol	87-86-5	1.0				19	15	0.4	C
Phenol	108-95-2	10,500						300,000	
Polychlorinated Biphenyls (PCBs)	1336-36-3	0.50			0.014	2	0.014	0.00064	C,P
Pyrene	129-00-0	1,050						30	
1,2,4,5-Tetrachlorobenzene	95-94-3							0.03	
1,1,2,2-Tetrachloroethane	79-34-5	1.8						30	C
Tetrachloroethylene	127-18-4	5						290	C,P
Toluene	108-88-3	1,000						520	
Toxaphene	8001-35-2	3				0.73	0.0002	0.0071	C
1,2-Trans-dichloroethylene	156-60-5	100						4,000	
Tributyltin (TBT)	Various					0.46	0.072		

Pollutant	CAS Number	DWS	Irr/Irr storage	LW	WH	Aquatic Life			Type
						Acute	Chronic	HH-OO	
1,2,4-Trichlorobenzene	120-82-1	70						0.76	C
1,1,1-Trichloroethane	71-55-6	200						200,000	
1,1,2-Trichloroethane	79-00-5	5						89	C
Trichloroethylene	79-01-6	5						70	C
2,4,5-Trichlorophenol	95-95-4							600	
2,4,6-Trichlorophenol	88-06-2	32						28	C
2-(2,4,5-Trichlorophenoxy)propionic acid (Silvex)	93-72-1							400	
Vinyl chloride	75-01-4	2						16	C

(2) Notes applicable to the table of numeric criteria in Paragraph (1) of this subsection.

(a) Where the letter "a" is indicated in a cell, the criterion is ~~hardness~~ based <u>on receiving water characteristics</u> and can be referenced in Subsection I of 20.6.4.900 NMAC.

(b) Where the letter "b" is indicated in a cell, the criterion can be referenced in Subsection C of 20.6.4.900 NMAC.

(c) Criteria are in µg/L unless otherwise indicated.

(d) Abbreviations are as follows: CAS - chemical abstracts service (see definition for "CAS number" in 20.6.4.7 NMAC); DWS - domestic water supply; Irr/Irr storage- irrigation and irrigation storage; LW - livestock watering; WH - wildlife habitat; HH-OO - human health-organism only; C – criteria based on cancer-causing endpoint; P - persistent toxic pollutant.

(e) The criteria are based on analysis of an unfiltered sample unless otherwise indicated. The acute and chronic aquatic life criteria for aluminum are based on analysis of total recoverable aluminum in a sample that is filtered to minimize mineral phases as specified by the department.

(f) The criteria listed under human health-organism only (HH-OO) are intended to protect human health when aquatic organisms are consumed from waters containing pollutants. These criteria do not protect the aquatic life itself; rather, they protect the health of humans who ingest fish or other aquatic organisms.

(g) The dioxin criteria apply to the sum of the dioxin toxicity equivalents expressed as 2,3,7,8-TCDD dioxin.

(h) The criteria for polychlorinated biphenyls (PCBs) apply to the sum of all congeners, to the sum of all homologs or to the sum of all aroclors.

(i) The acute and chronic aquatic life criteria for dissolved aluminum only apply when the concurrent pH is less than 6.5 or greater than 9.0 S.U. If the concurrent pH is between 6.5 and 9.0 S.U. then the hardness-dependent total recoverable aluminum criteria in Paragraphs (1) and (2) of Subsection I of 20.6.4.900 NMAC apply.

K. The criteria for total ammonia consider sensitive freshwater mussel species in the family Unionidae, freshwater non-pulmonate snails, and *Oncorhynchus* spp. (a genus of fish in the family Salmonidae), hence further protecting the aquatic community. The total ammonia criteria magnitude is measured as Total Ammonia Nitrogen (TAN) mg/L. TAN is the sum of NH_4^+ and NH_3. TAN mg/L magnitude is derived as a function of pH and temperature (EPA 2013).

L. The acute aquatic life criteria for TAN (mg/L) was derived by the EPA (2013) as the one-hour average concentration of TAN mg/L that shall not be exceeded more than once every three years on average. The EPA acute criterion magnitude was derived using the following equation:

Acute TAN Criterion Magnitude for 1-hour average=

$$\text{MIN}\left(\begin{array}{c}\left(\frac{0.275}{1+10^{7.204-pH}}+\frac{39}{1+10^{pH-7.204}}\right),\\ \left(0.7249\text{x}\left(\frac{0.0114}{1+10^{7.204-pH}}+\frac{1.6181}{1+10^{pH-7.204}}\right)\text{x}\left(23.12\times10^{0.036(20-T)}\right)\right)\end{array}\right)$$

T (temperature C) and *pH* are defined as the paired values associated with the TAN sample.

(1) Temperature and pH-dependent values of the acute TAN criterion magnitude -when *Oncorhynchus* spp. absent.

	Temperature (°C)																				
pH	0-10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	51	48	44	41	37	34	32	29	27	25	23	21	19	18	16	15	14	13	12	11	9.9
6.6	49	46	42	39	36	33	30	28	26	24	22	20	18	17	16	14	13	12	11	10	9.5
6.7	46	44	40	37	34	31	29	27	24	22	21	19	18	16	15	14	13	12	11	9.8	9
6.8	44	41	38	35	32	30	27	25	23	21	20	18	17	15	14	13	12	11	10	9.2	8.5
6.9	41	38	35	32	30	28	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9
7.0	38	35	33	30	28	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9	7.3
7.1	34	32	30	27	25	23	21	20	18	17	15	14	13	12	11	10	9.3	8.5	7.9	7.2	6.7
7.2	31	29	27	25	23	21	19	18	16	15	14	13	12	11	9.8	9.1	8.3	7.7	7.1	6.5	6
7.3	27	26	24	22	20	18	17	16	14	13	12	11	10	9.5	8.7	8	7.4	6.8	6.3	5.8	5.3
7.4	24	22	21	19	18	16	15	14	13	12	11	9.8	9	8.3	7.7	7	6.5	6	5.5	5.1	4.7
7.5	21	19	18	17	15	14	13	12	11	10	9.2	8.5	7.8	7.2	6.6	6.1	5.6	5.2	4.8	4.4	4
7.6	18	17	15	14	13	12	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5
7.7	15	14	13	12	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5	3.2	2.9
7.8	13	12	11	10	9.3	8.5	7.9	7.2	6.7	6.1	5.6	5.2	4.8	4.4	4	3.7	3.4	3.2	2.9	2.7	2.5
7.9	11	9.9	9.1	8.4	7.7	7.1	6.6	3	5.6	5.1	4.7	4.3	4	3.7	3.4	3.1	2.9	2.6	2.4	2.2	2.1
8.0	8.8	8.2	7.6	7	6.4	5.9	5.4	5	4.6	4.2	3.9	3.6	3.3	3	2.8	2.6	2.4	2.2	2	1.9	1.7
8.1	7.2	6.8	6.3	5.8	5.3	4.9	4.5	4.1	3.8	3.5	3.2	3	2.7	2.5	2.3	2.1	2	1.8	1.7	1.5	1.4
8.2	6	5.6	5.2	4.8	4.4	4	3.7	3.4	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2
8.3	4.9	4.6	4.3	3.9	3.6	3.3	3.1	2.8	2.6	2.4	2.2	2	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1	0.96
8.4	4.1	3.8	3.5	3.2	3	2.7	2.5	2.3	2.1	2	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1	0.93	0.86	0.79
8.5	3.3	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	0.98	0.9	0.83	0.77	0.71	0.65
8.6	2.8	2.6	2.4	2.2	2	1.9	1.7	1.6	1.5	1.3	1.2	1.1	1	0.96	0.88	0.81	0.75	0.69	0.63	0.58	0.54
8.7	2.3	2.2	2	1.8	1.7	1.6	1.4	1.3	1.2	1.1	1	0.94	0.87	0.8	0.74	0.68	0.62	0.57	0.53	0.49	0.45
8.8	1.9	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37
8.9	1.6	1.5	1.4	1.3	1.2	1.1	1	0.93	0.85	0.79	0.72	0.67	0.61	0.56	0.52	0.48	0.44	0.4	0.37	0.34	0.32
9.0	1.4	1.3	1.2	1.1	1	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37	0.34	0.32	0.29	0.27

(2) Temperature and pH-dependent values for the acute TAN criterion magnitude- when *Oncorhynchus* spp. are present.

	Temperature (°C)																
pH	0-14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	33	33	32	29	27	25	23	21	19	18	16	15	14	13	12	11	9.9
6.6	31	31	30	28	26	24	22	20	18	17	16	14	13	12	11	10	9.5
6.7	30	30	29	27	24	22	21	19	18	16	15	14	13	12	11	9.8	9
6.8	28	28	27	25	23	21	20	18	17	15	14	13	12	11	10	9.2	8.5
6.9	26	26	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9
7.0	24	24	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	8	7.3
7.1	22	22	21	20	18	17	15	14	13	12	11	10	9.3	8.5	7.9	7.2	6.7
7.2	20	20	19	18	16	15	14	13	12	11	9.8	9.1	8.3	7.7	7.1	6.5	6
7.3	18	18	17	16	14	13	12	11	10	9.5	8.7	8	7.4	6.8	6.3	5.8	5.3
7.4	15	15	15	14	13	12	11	9.8	9	8.3	7.7	7	6.5	6	5.5	5.1	4.7
7.5	13	13	13	12	11	10	9.2	8.5	7.8	7.2	6.6	6.1	5.6	5.2	4.8	4.4	4
7.6	11	11	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5

7.7	9.6	9.6	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5	3.2	3
7.8	8.1	8.1	7.9	7.2	6.7	6.1	5.6	5.2	4.8	4.4	4	3.7	3.4	3.2	2.9	2.7	2.5
7.9	6.8	6.8	6.6	6	5.6	5.1	4.7	4.3	4	3.7	3.4	3.1	2.9	2.6	2.4	2.2	2.1
8.0	5.6	5.6	5.4	5	4.6	4.2	3.9	3.6	3.3	3	2.8	2.6	2.4	2.2	2	1.9	1.7
8.1	4.6	4.6	4.5	4.1	3.8	3.5	3.2	3	2.7	2.5	2.3	2.1	2	1.8	1.7	1.5	1.4
8.2	3.8	3.8	3.7	3.5	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2
8.3	3.1	3.1	3.1	2.8	2.6	2.4	2.2	2	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1	1
8.4	2.6	2.6	2.5	2.3	2.1	2	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1	0.9	0.9	0.8
8.5	2.1	2.1	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	1	0.9	0.8	0.8	0.7	0.7
8.6	1.8	1.8	1.7	1.6	1.5	1.3	1.2	1.1	1	1	0.9	0.8	0.8	0.7	0.6	0.6	0.5
8.7	1.5	1.5	1.4	1.3	1.2	1.1	1	0.9	0.9	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.5
8.8	1.2	1.2	1.2	1.1	1	0.9	0.9	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.4
8.9	1	1	1	0.9	0.9	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.4	0.3	0.3
9.0	0.88	0.9	0.9	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.4	0.3	0.3	0.3	0.3

M. The chronic aquatic life criteria for TAN (mg/L) was derived by the EPA (2013) as a thirty-day rolling average concentration of TAN mg/L that shall not be exceeded more than once every three years on average. In addition, the highest four-day average within the 30-day averaging period should not be more than 2.5 times the CCC (e.g., 2.5 x 1.9 mg TAN/L at pH 7 and 20°C, or 4.8 mg TAN/L) more than once in three years on average. The EPA chronic criterion magnitude was derived using the following equation:

Chronic TAN Criterion Magnitude for 30-day average=

$$0.8876 \times \left(\frac{0.0278}{1+10^{7.688-pH}} + \frac{1.1994}{1+10^{pH-7.688}}\right) \times \left(2.126 \times 10^{0.028\times(20-MAX(T,7))}\right)$$

*T (*temperature °C) and *pH* are defined as the paired values associated with the TAN sample.

Temperature and pH-Dependent Values of the Chronic TAN Criterion Magnitude.

	Temperature (°C)																						
pH	0-7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	4.9	4.6	4.3	4.1	3.8	3.6	3.3	3.1	2.9	2.8	2.6	2.4	2.3	2.1	2	1.9	1.8	1.6	1.5	1.5	1.4	1.3	1.2	1.1
6.6	4.8	4.5	4.3	4	3.8	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1
6.7	4.8	4.5	4.2	3.9	3.7	3.5	3.2	3	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1
6.8	4.6	4.4	4.1	3.8	3.6	3.4	3.2	3	2.8	2.6	2.4	2.3	2.1	2	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1
6.9	4.5	4.2	4	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1
7.0	4.4	4.1	3.8	3.6	3.4	3.2	3	2.8	2.6	2.4	2.3	2.2	2	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1
7.1	4.2	3.9	3.7	3.5	3.2	3	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1	1
7.2	4	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1	1	0.9
7.3	3.8	3.5	3.3	3.1	2.9	2.7	2.6	2.4	2.2	2.1	2	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1	1	0.9	0.9
7.4	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1	1	0.9	0.9	0.8
7.5	3.2	3	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1	1	0.9	0.8	0.8	0.7
7.6	2.9	2.8	2.6	2.4	2.3	2.1	2	1.9	1.8	1.6	1.5	1.4	1.4	1.3	1.2	1.1	1.1	1	0.9	0.9	0.8	0.8	0.7	0.7
7.7	2.6	2.4	2.3	2.2	2	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6
7.8	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1	1	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.5
7.9	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1	1	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.5	0.5	0.5
8.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.4	0.4	0.4
8.1	1.5	1.5	1.4	1.3	1.2	1.1	1.1	1	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4
8.2	1.3	1.2	1.2	1.1	1	1	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3
8.3	1.1	1.1	1	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
8.4	1	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2

8.5	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
8.6	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
8.7	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1
8.8	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
8.9	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
9.0	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

[20.6.4.900 NMAC - Rp 20 NMAC 6.1.3100, 10/12/2010; A, 10/11/2002; A, 5/23/2005; A, 7/17/2005; A, 12/1/2010; A, 3/2/2017; A, 4/23/2022]

20.6.4.901 PUBLICATION REFERENCES: These documents are intended as guidance and are available for public review during regular business hours at the offices of the surface water quality bureau. Copies of these documents have also been filed with the New Mexico state records center in order to provide greater access to this information.

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[20.6.4.901 NMAC - Rp 20 NMAC 6.1.4000, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017; A, 4/23/2022]

HISTORY of 20.6.4 NMAC:

Pre-NMAC History:

Material in the part was derived from that previously filed with the commission of public records - state records center and archives:

WQC 67-1, Water Quality Standards, filed 7/17/1967, effective 8/18/1967

WQC 67-1, Amendment Nos. 1-6, filed 3/21/1968, effective 4/22/1968
WQC 67-1, Amendment No. 7, filed 2/27/1969, effective 3-30/1969
WQC 67-1, Amendment No. 8, filed 7/14/1969, effective 8/15/1969
WQC 70-1, Water Quality Standards for Intrastate Waters and Tributaries to Interstate Streams, filed July 17, 1970;
WQC 67-1, Amendment Nos. 9 and 10, filed 2/12/1971, effective 3/15/1971
WQC 67-1, Amendment No. 11, filed 3/4/1971, effective 4/5/1971
WQC 73-1, New Mexico Water Quality Standards, filed 9/17/1973, effective 10/23/1973
WQC 73-1, Amendment Nos. 1 and 2, filed 10/3/1975, effective 11/4/1975
WQC 73-1, Amendment No. 3, filed 1/19/1976, effective 2/14/1976
WQC 77-2, Amended Water Quality Standards for Interstate and Intrastate Streams in New Mexico, filed 2/24/1977, effective 3/11/1977
WQC 77-2, Amendment No. 1, filed 3/23/1978, effective 4/24/1978
WQC 77-2, Amendment No. 2, filed 6/12/1979, effective 7/13/1979
WQCC 80-1, Water Quality Standards for Interstate and Intrastate Streams in New Mexico, filed 8/28/1980, effective 9/28/1980
WQCC 81-1, Water Quality Standards for Interstate and Intrastate Streams in New Mexico, filed 5/5/1981, effective 6/4/1981
WQCC 81-1, Amendment No. 1, filed 5/19/1982, effective 6/18/1982
WQCC 81-1, Amendment No. 2, filed 6/24/1982, effective 7/26/1982
WQCC 85-1, Water Quality Standards for Interstate and Intrastate Streams in New Mexico, filed 1/16/1985, effective 2/15/1985
WQCC 85-1, Amendment No. 1, filed 8/28/1987, effective 9/28/1987
WQCC 88-1, Water Quality Standards for Interstate and Intrastate Streams in New Mexico, filed 3/24/1988, effective 4/25/1988
WQCC 91-1, Water Quality Standards for Interstate and Intrastate Streams in New Mexico, filed 5/29/1991, effective 6/29/1991
WQCC 91-1, Amendment No. 1, filed 10/11/1991, effective 11/12/1991

History of the Repealed Material:
WQC 67-1, Water Quality Standards, - Superseded, 10/23/1973
WQC 73-1, New Mexico Water Quality Standards, - Superseded, 3/11/1977
WQC 77-2, Amended Water Quality Standards for Interstate and Intrastate Streams in New Mexico, - Superseded, 9/28/1980
WQCC 80-1, Water Quality Standards for Interstate and Intrastate Streams in New Mexico, - Superseded, 6/4/1981
WQCC 81-1, Water Quality Standards for Interstate and Intrastate Streams in New Mexico, - Superseded, 2/15/1985
WQCC 85-1, Water Quality Standards for Interstate and Intrastate Streams in New Mexico, - Superseded, 4/25/1988
WQCC 88-1, Water Quality Standards for Interstate and Intrastate Streams in New Mexico, - Superseded, 6/29/1991
WQCC 91-1, Water Quality Standards for Interstate and Intrastate Streams in New Mexico, - Superseded, 1/23/1995
20 NMAC 6.1, Standards for Interstate and Intrastate Streams, - Repealed, 2/23/2000
20 NMAC 6.1, Standards for Interstate and Intrastate Surface Waters, - Repealed, 10/12/2000

STATE OF NEW MEXICO
BEFORE THE WATER QUALITY CONTROL COMMISSION

IN THE MATTER OF:

THE PETITION TO AMEND
THE STANDARDS FOR INTERSTATE
AND INTRASTATE SURFACE WATERS,
20.6.4 NMAC **WQCC No. 24-31(R)**

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

Petitioners.

DIRECT TESTIMONY OF AMANDA B. WHITE
ON BEHALF OF TRIAD NATIONAL SECURITY, LLC, NEWPORT NEWS NUCLEAR BWXT-LOS ALAMOS, LLC, AND THE U.S. DEPARTMENT OF ENERGY, OFFICE OF ENVIRONMENTAL MANAGEMENT LOS ALAMOS FIELD OFFICE

December 20, 2024

I. INTRODUCTION

Q. PLEASE STATE YOUR NAME AND BUSINESS ADDRESS.

A. My name is Amanda B. White. My business address is 1200 Trinity Drive, Suite 150, Los Alamos, NM 87544.

Q. ON WHOSE BEHALF ARE YOU SUBMITTING DIRECT TESTIMONY?

A. I am submitting this direct testimony on behalf of Triad National Security, LLC (“Triad”), Newport News Nuclear BWXT-Los Alamos, LLC (“N3B”) and the U.S. Department of Energy (“DOE”), Office of Environmental Management Los Alamos Field Office (“DOE EM-LA”) (collectively “Petitioners”).

Q. PLEASE DESCRIBE PETITIONERS.

A. Triad is comprised of three non-profit entities: Battelle Memorial Institute; the University of California; and the Texas A&M University System. Triad manages and operates the Los Alamos National Laboratory (“LANL”) on behalf of DOE, National Nuclear Security Administration (“DOE/NNSA”) pursuant to Contract No. 89233218CNA000001.

N3B manages the Los Alamos Legacy Cleanup at LANL under contract with DOE EM-LA. DOE EM-LA is responsible for the cleanup of legacy contamination left behind by nuclear weapons production and research during the Manhattan Project and Cold War era at LANL. DOE EM-LA’s cleanup mission includes legacy waste remediation and disposition, soil and groundwater remediation, and deactivation and decommissioning of excess buildings and facilities.

Q. BY WHOM ARE YOU EMPLOYED AND WHAT IS YOUR POSITION?

A. I am currently employed as the Director of Tech2 Solutions for the Los Alamos Legacy Cleanup Contract at LANL and have held that position for the last one and a half years. N3B relies on Tech2 Solutions as a critical subcontractor to N3B for the legacy cleanup at LANL and is responsible for planning and executing environmental monitoring programs, including for groundwater and surface water.

Q. PLEASE SUMMARIZE YOUR RELEVANT EDUCATIONAL AND PROFESSIONAL EXPERIENCE.

A. I hold a Bachelor of Science Degree in Civil Engineering from Old Dominion University, and a Master of Science Degree and Ph.D. in Civil and Environmental Engineering from the University of Illinois at Urbana-Champaign. I also have over 18 years professional experience related to sitewide groundwater and surface water monitoring at LANL in support of the 2005 Compliance Order on Consent and the 2016 Compliance Order on Consent, as revised in 2024, between NMED and DOE. As mentioned above, I have been the Director of Tech2 Solutions since July 2023 and currently lead the Tech2 Solutions water program under DOE EM-LA's Los Alamos Legacy Cleanup Contract. Prior to that, I worked for Tech2 Solutions since 2018 in various roles of increasing responsibility (Project Manager for Surface Water Monitoring [2018 to 2020], Program Manager for Surface Water and Individual Permit Monitoring [2020 to 2022], Deputy Director [2022 to 2023], and Director [2023-2024]).

Prior to being employed by Tech2 Solutions, I was employed by Los Alamos National Security ("LANS"), LLC, for approximately 12 years. I worked in the Associate

Directorate of Environmental Management, Surface Water Program, from 2010 to 2018, where I served as the surface water hydrologist and operated and maintained LANL's streamflow gaging station network, among other responsibilities. Prior to that, I was a postdoctoral candidate from 2006 to 2010 researching the ecological-hydrological interactions before and after large-scale tree mortality.

Q. WHAT ARE YOUR RESPONSIBILITIES AT TECH2 SOLUTIONS THAT ARE RELEVANT TO THIS PETITION?

A. My responsibilities include: (i) managing surface water and stormwater monitoring and environmental compliance under the EPA Storm Water Individual Permit NPDES No. NM0030759 (managed and owned by Permittees N3B and DOE EM-LA), 2016 Compliance Order on Consent, as revised in 2024, between NMED and DOE, DOE/Buckman Direct Diversion Board Memorandum of Understanding, and DOE Environmental Surveillance Program; (ii) managing development of compliance reports for N3B and DOE EM-LA to be submitted to NMED, EPA and other regulatory agencies; (iii) managing stormwater monitoring and best management practice inspections at 239 site monitoring areas; and (iv) managing the operation and sampling of 37 streamflow gaging stations across LANL, including developing sample plans and standard operating procedures for field sample collection and preservation.

Q. HAVE YOU PREVIOUSLY TESTIFIED BEFORE THIS COMMISSION?

A. No.

Q. ARE YOU SPONSORING ANY EXHIBITS?

A. Yes, throughout my testimony I refer to information presented in the *Copper Site-Specific Water Quality Criteria for the Pajarito Plateau: Demonstration Report* ("Demonstration Report"), provided as **Petitioners' Exhibit 1**.

II. PURPOSE OF TESTIMONY

Q. WHAT IS THE PURPOSE OF YOUR TESTIMONY?

A. The purpose of my testimony is to identify the surface waters within the geographic area referred to as the Pajarito Plateau that will be covered by the proposed amendments. My testimony explains the development of the proposals, through discussions with NMED and EPA and a public comment process, and provides support for Petitioners' proposed amendments to the New Mexico Water Quality Control Commission's ("WQCC") Standards for Interstate and Intrastate Surface Waters, 20.6.4 NMAC ("Standards") to add site-specific water quality criteria ("SSWQC") for copper for surface waters within the geographic area referred to as the Pajarito Plateau. Specifically, my testimony provides background and context for the proposed amendment in the following ways:

- I provide background information on the surface waters in the Pajarito Plateau to which the proposed copper SSWQC would apply.
- I summarize the reason for developing the proposed copper SSWQC for these surface waters and describe collection of data used to support the proposed copper SSWQC.

- I summarize Petitioners' outreach and extended engagement with the Department's Surface Water Quality Bureau ("SWQB"), the EPA, stakeholders, pueblos, and the public in developing this proposed copper SSWQC.

III. BACKGROUND ON SURFACE WATERS WITHIN PAJARITO PLATEAU

Q. PLEASE PROVIDE AN OVERVIEW OF THE PAJARITO PLATEAU SURFACE WATERS THAT ARE THE SUBJECT OF THIS APPLICATION.

A. A depiction of the Pajarito Plateau and surface waters is shown in Figures A and B below, replicated from Figure 3-1 and Map 3-1 in the Demonstration Report (**Petitioners' Exhibit 1**). The depicted area includes land within the LANL boundaries, Los Alamos County, and the Pueblo de San Ildefonso and encompasses all or part of seven major watersheds that drain into the Rio Grande basin. Each of these watersheds includes tributary canyons of various sizes. Sources of surface water in these watersheds include snowmelt, stormwater runoff, treated effluent, and discharges at springs. The seven watersheds within this area encompass approximately 80 miles of surface waters.

Q. ARE THE PAJARITO PLATEAU SURFACE WATERS CLASSIFIED AS SURFACE WATERS OF THE STATE?

A. Yes. The Pajarito Plateau surface waters are classified in 20.6.4 NMAC as surface waters of the state. Classifications and aquatic life use designations are specific to the hydrologic regime of a waterbody (i.e., ephemeral, intermittent, or perennial). Most surface water drainages within the Pajarito Plateau are currently classified as ephemeral or intermittent at 20.6.4.128 NMAC because streamflow only occurs for limited periods in response to rainfall or snowmelt. Summer monsoonal thunderstorms are the sole contributors to streamflow in many of the ephemeral waters, which otherwise remain dry for most of the year. The designated uses for these waters include livestock watering, wildlife habitat, limited aquatic life and secondary contact.

Only a few surface water drainages on the Pajarito Plateau are classified as perennial (20.6.4.121 and 20.6.4.126 NMAC). The designated uses for these waters include domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat, and primary contact for surface waters classified at 20.6.4.121 NMAC[1]; and coldwater aquatic life, livestock watering, wildlife habitat, and secondary contact for surface waters classified at 20.6.4.126 NMAC.

Other surface water drainages on the Pajarito Plateau are unclassified non-perennial waters of the state that are not identified in 20.6.4.101 through 20.6.4.899 NMAC. The designated uses applicable to these surface waters are provided at 20.6.4.98 NMAC and include livestock watering, wildlife habitat, marginal warmwater aquatic life, and primary contact.

As described in Barry Fulton's testimony, the proposed copper SSWQC would only apply to aquatic life use designations for surface waters of the Pajarito Plateau; the proposed copper SSWQC would not affect existing designated uses or existing criteria specified for the protection of designated uses other than aquatic life.

Q. BRIEFLY DESCRIBE THE EXISTING AQUATIC LIFE COPPER CRITERIA APPLICABLE TO THE WATERS OF THE PAJARITO PLATEAU

[1] Specified designated uses are for those surface waters in 20.6.4.121 NMAC that occur on the Pajarito Plateau.

A. The existing statewide copper criteria set forth in 20.6.4.900 NMAC currently apply to these waters. These criteria are referred to as "hardness-based criteria" because they only account for the effects of hardness on copper toxicity to aquatic life, as described in Barry Fulton's testimony.

Q. PLEASE DESCRIBE THE PROPOSAL TO CHANGE THOSE CRITERIA?

A. The proposal, as filed with the Petition, is provided as **Petitioners' Exhibit 2**. Petitioners are seeking amendments to 20.6.4.900 NMAC to add copper SSWQC for Pajarito Plateau surface waters. These proposed amendments are consistent with EPA's current recommendations for copper aquatic life criteria and WQCC's provisions for developing site-specific aquatic life criteria. The proposed copper SSWQC were developed using EPA's Biotic Ligand Model ("BLM"), which is a bioavailability software model that uses the best available science to account for the effects of multiple water chemistry parameters on the bioavailability and toxicity of copper to aquatic life. The copper SSWQC are proposed as equations that accurately calculate the BLM software criteria. Barry Fulton's testimony describes the proposed new criteria.

Q. WHY ARE PETITIONERS PROPOSING TO CHANGE THE COPPER CRITERIA FOR THESE WATERS?

A. Petitioners are proposing the change to incorporate the best available science and current EPA recommendations for copper criteria.

IV. DATA COLLECTION AND DEVELOPMENT OF SSWQC FOR COPPER

Q. PLEASE DESCRIBE EFFORTS AT LANL TO COLLECT COPPER BLM DATA FOR PAJARITO PLATEAU SURFACE WATERS?

A. Petitioners conduct various surface water quality monitoring programs at many locations on the Pajarito Plateau. The programs are typically related to permit compliance monitoring and monitoring required under the 2016 Compliance Order on Consent, as revised in 2024, although periodic investigative studies are also conducted to better understand and manage surface waters on the Pajarito Plateau.

In 2007, EPA published updated aquatic life criteria for copper that utilize the BLM. Petitioners have collected ambient surface water samples for BLM parameters for approximately 20 years. As a result, Petitioners have a robust dataset that supports implementation of BLM-based copper criteria for surface waters on the Pajarito Plateau, consistent with EPA's recommendations.

Petitioners sought support from Windward Environmental LLC ("Windward") on the design and implementation of the surface water monitoring programs that collected BLM water quality parameters. These surface water monitoring programs have enabled Petitioners to implement EPA's aquatic life criteria for copper and develop the copper SSWQC, which are the subject of this hearing. Windward is recognized for its expertise in metals criteria development and implementation, particularly with respect to the BLM.

Q. HOW WAS THE QUALITY OF THE DATA CONTROLLED AND ASSURED?

A. Although surface water samples are sometimes collected as discrete grab samples, most samples were collected through a network of automated pump samplers (APS) located at various streamflow gaging stations. These devices are triggered when there is sufficient streamflow, often generated by a summer monsoonal storm event. When there is sufficient flow, an internal pump activates, drawing surface water into a series of sample bottles that remain in the APS until collected by a field technician (typically within 24 to 48 hours). Regardless of the sampling method, all samples are collected in pre-cleaned bottles to prevent contamination. The technician delivers the bottles to a sample processing facility, where each bottle is refrigerated, filtered, and/or chemically preserved as appropriate for the target analytes. Next, the sample is transferred to the sample management office and finally to an independent, third-party contract laboratory for chemical analysis. This process utilizes strict chain of custody ("COC") documentation from when the sample is retrieved from the field to when it arrives at the laboratory, and is carried out by trained and qualified personnel under approved standard operating procedures.

Petitioners maintained quality control/quality assurance ("QA/QC") measures during the sampling and transport processes, including the use of COC forms to track the collection and delivery of samples to laboratories. N3B/DOE third-party contract laboratories follow standard QA/QC procedures for analysis and data reporting. These laboratories are accredited under the DOE Consolidated Audit Program for the analytes of interest. Detection and reporting limits are provided with samples, and non-detections are flagged by the laboratory and checked by independent data validators. Laboratory analytical data is also validated by N3B to a series of guidelines based on EPA's QA/G-8 Guidance on Environmental Data Verification and Data Validation (EPA 2002), the Department of Defense/Department of Energy Consolidated Quality Systems Manual

(QSM) for Environmental Laboratories (DoD and DOE 2019), and the EPA national functional guidelines for data validation (EPA 2017, 2020).

Q. WHAT WERE THE NEXT STEPS TO DEVELOP PETITIONERS' PROPOSAL

A. Windward was engaged to prepare the Demonstration Report (**Petitioners' Exhibit 1**). The technical work is covered in Barry Fulton's testimony.

V. OUTREACH

Q. PLEASE SUMMARIZE PETITIONERS' ENGAGEMENT WITH NMED AND EPA DURING DEVELOPMENT OF THE PROPOSED AMENDMENT?

A. The following table summarizes meetings, reporting, and response to comments among Petitioners, NMED, and EPA.

Date	Engagement	Participants
January 25, 2018	Meeting in Santa Fe, NM to provide overview of the copper BLM and discuss its application to Pajarito Plateau Surface Waters	NMED, Petitioners, Windward
October 24, 2018	Webinar on the application of BLM to Pajarito Plateau Surface Waters	NMED, Petitioners, Windward
April 10, 2020	Virtual meeting on application of BLM to Pajarito Plateau Surface Waters	NMED, DOE EM-LA, N3B, Windward
July 7, 2020	DOE EM-LA and N3B submitted work plan for development of copper SSWQC based on BLM for Pajarito Plateau surface waters	Submitted to NMED
September 9, 2020	Meeting with NMED regarding status and next steps for copper SSWQC	NMED, DOE EM-LA, N3B, Windward
March 9, 2021	NMED provided comments to DOE EM-LA and N3B on the draft copper SSWQC work plan	NMED, DOE EM-LA, N3B, Windward
July 28, 2021	DOE EM-LA and N3B submitted draft Demonstration Report	Submitted to NMED and EPA

Date	Engagement	Participants
November 9, 2021	NMED and EPA provided comments and requested additional information for the draft Demonstration Report	Comments provided to DOE EM-LA and N3B
May 31, 2022	DOE EM-LA and N3B submitted a revised draft of the Demonstration Report and additional information requested by NMED	Submitted to NMED
March 31, 2023	NMED and EPA provided additional comments on the draft Demonstration Report	Comments provided to DOE EM-LA and N3B
June 29, 2023	Teleconference with NMED to discuss comments on the draft Demonstration Report and path forward	NMED, DOE EM-LA, N3B, Windward
August 24, 2023	DOE EM-LA and N3B submitted a second revised draft of the Demonstration Report and response to comments	Submitted to NMED and EPA
April 11, 2024	Teleconference to discuss draft petition for copper SSWQC	NMED, DOE EM-LA, N3B, Windward

Q. DID PETITIONERS PROVIDE THE DRAFT PETITION TO NMED BEFORE FILING WITH THE COMMISSION?

A. Yes. Petitioners provided the draft petition to NMED on April 15, 2024, to request feedback on their preference for amending 20.6.4 NMAC to include the copper SSWQC. The filed petition incorporates NMED's recommendations to include the proposed copper SSWQC equations for Pajarito Plateau surface waters in 20.6.4.900 NMAC.

Q. PLEASE DESCRIBE PETITIONERS' PUBLIC INVOLMENT PLAN TO INFORM STAKEHOLDERS AND MEMBERS OF THE PUBLIC OF THE PROPOSED CHANGE.

A. Petitioners developed a Public Involvement Plan to provide a process for public, tribal, and stakeholder engagement for development of the copper SSWQC. The Plan was provided to NMED for review and comment. The Plan identifies the information, activities, and schedule to solicit participation from the various entities and is provided as Appendix C to **Petitioners' Exhibit 1**.

Q. WAS THE PROPOSED COPPER SSWQC PRESENTED TO STAKEHOLDERS, PUEBLOS, AND THE GENERAL PUBLIC BEFORE THE APPLICATION WAS FILED?

A. Yes. For the past four years, DOE EM-LA and N3B have been presenting the proposed change to the copper criteria in various public platforms to various stakeholders that are likely to be impacted by the change. This includes a 45-day public comment period (**Petitioners' Exhibit 7**) and responding to public comments on the Demonstration Report following the September 26, 2023, Public Meeting, as identified below:

Date of Meeting	Meeting Title	Stakeholders, Pueblos, and Members of the Public
December 16, 2020	Individual NPDES Stormwater Permit Public Meeting	General Public
May 19, 2021	Northern New Mexico Communities Action Board (NNMCAB) Meeting	City of Santa Fe, Los Alamos County, Pueblo of Pojoaque, Pueblo de San Ildefonso, Five Sandoval Indian Pueblos, New Mexico Highlands University, Amigos Bravos, and private entities
June 16, 2021	Individual NPDES Stormwater Permit Public Meeting	General Public
November 9, 2021	Accord Pueblo Technical Exchange Meeting	Pueblo de San Ildefonso, Pueblo of Jemez, and Pueblo of Santa Clara
November 23, 2021	Eastern Jemez Resource Council (EJRC) Meeting	NPS, USDA, NMED, USGS, DOE NNSA, USACE, Los Alamos County, Pueblo of Cochiti, Pueblo de San Ildefonso, Pueblo of Jemez, Pueblo of Santa Clara, Rio Grande Return, Trees Water & People, Various

Date of Meeting	Meeting Title	Stakeholders, Pueblos, and Members of the Public
		Universities, and Pajarito Environmental Education Center
November 30, 2021	Individual NPDES Stormwater Permit Public Meeting	General Public
March 9, 2022	Los Alamos County Board of Public Utilities Working Session Meeting	Los Alamos County and the General Public
September 26, 2023	Public Meeting on Demonstration Report	General Public

Q. DID PETITIONERS CONSIDER AND RESPOND TO INPUT PROVIDED BY STAKEHOLDERS, PUEBLOS, AND MEMBERS OF THE PUBLIC?

A. Yes. Petitioners' responses to comments received during the 45-day public comment period are provided in **Petitioners' Exhibit 8**.

VI. CONCLUSION

Q. PLEASE SUMMARIZE YOUR RECOMMENDATION TO THE COMMISSION.

A. I recommend the Commission adopt Petitioners' proposed copper SSWQC for Pajarito Plateau surface waters to incorporate the best available science and current EPA recommendations for copper criteria.

Q. DOES THIS CONCLUDE YOUR DIRECT TESTIMONY?

A. Yes.

Figure A. Map 3-1 from the Demonstration Report (Petitioners' Exhibit 1)

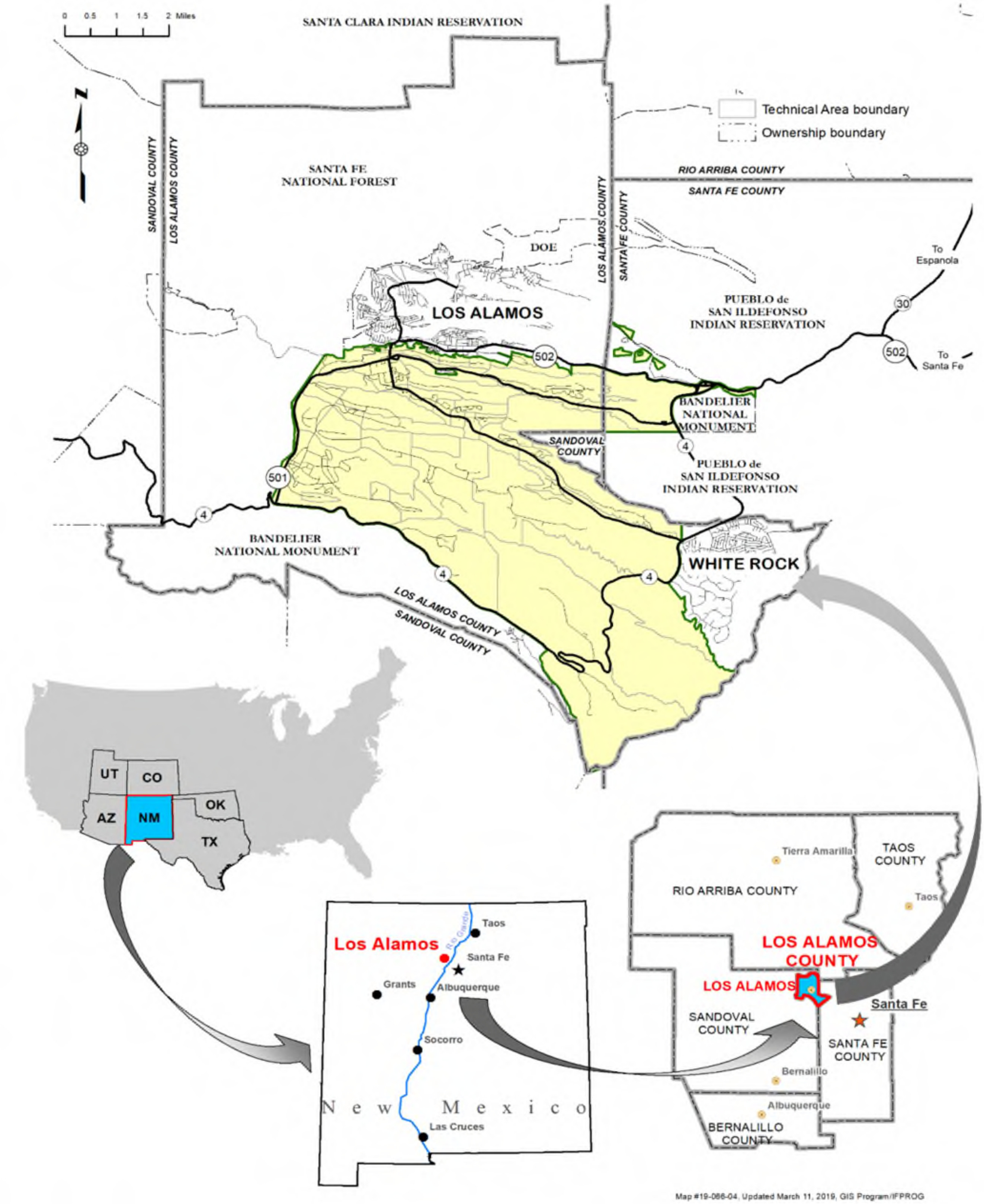
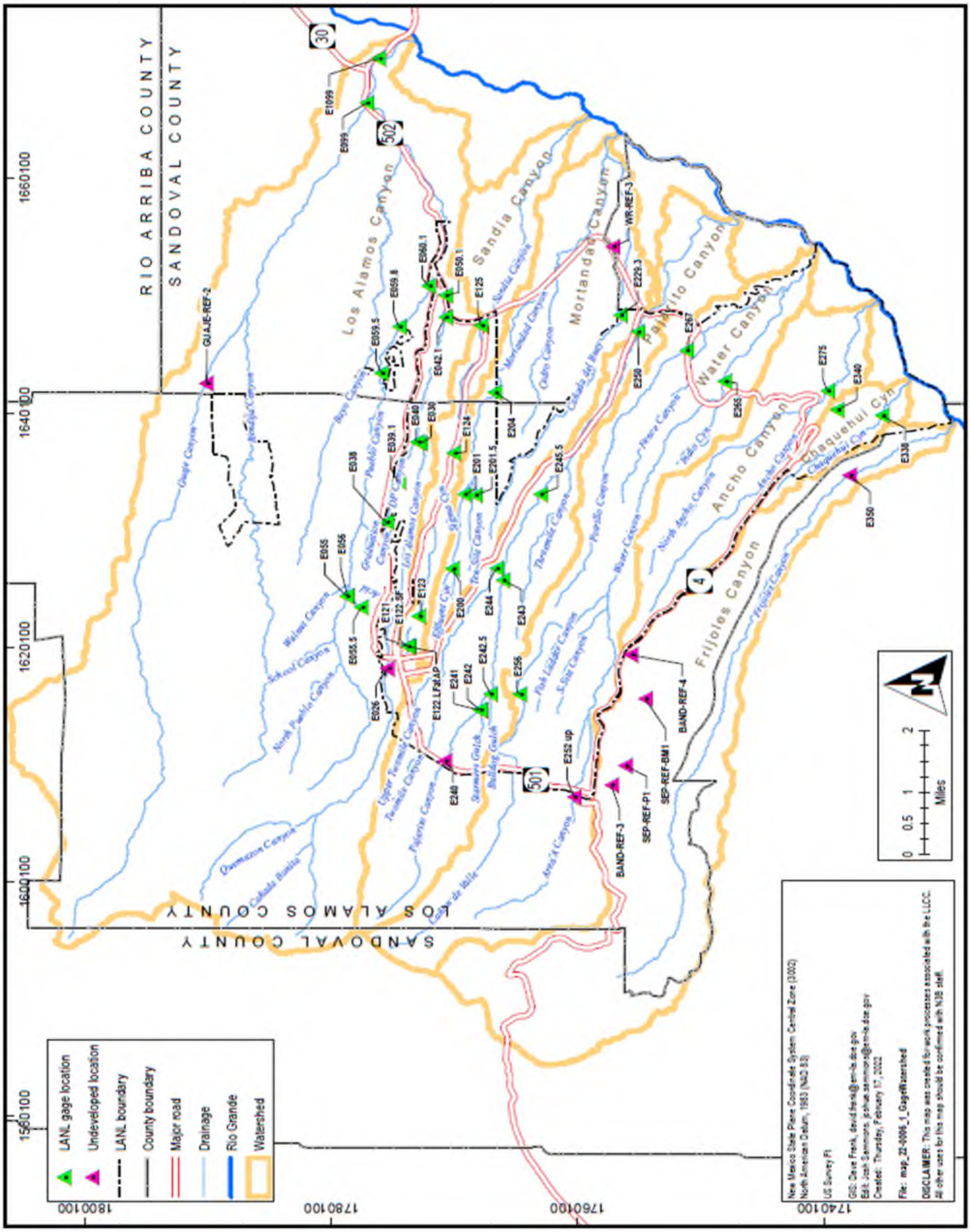


Figure B. Map 3-1 from the Demonstration Report (Petitioners' Exhibit 1)



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

Petitioners.

DIRECT TESTIMONY OF BARRY FULTON, BENCHMARK ENVIRONMENTAL, LLC, ON BEHALF OF TRIAD NATIONAL SECURITY, LLC, NEWPORT NEWS NUCLEAR BWXT-LOS ALAMOS, LLC, AND THE U.S. DEPARTMENT OF ENERGY, OFFICE OF ENVIRONMENTAL MANAGEMENT Los Alamos Field Office

December 20, 2024

PETITIONERS' EXHIBIT 4

I. INTRODUCTION

Q. PLEASE STATE YOUR NAME AND BUSINESS ADDRESS.

A. My name is Barry Fulton. I am the Principal Scientist and Owner of Benchmark Environmental, LLC ("Benchmark") and an affiliate of Windward Environmental LLC ("Windward"). My business address is 51 Fawnlilly Drive, McCall, Idaho 83638.

Q. ON WHOSE BEHALF ARE YOU SUBMITTING DIRECT TESTIMONY?

A. I am submitting this direct testimony on behalf of Triad National Security, LLC, ("Triad"), Newport News Nuclear BWXT-Los Alamos, LLC ("N3B"), and the United States Department of Energy, Office of Environmental Management Los Alamos Field Office ("EM-LA") (collectively "Petitioners").

Q. PLEASE SUMMARIZE YOUR RELEVANT EDUCATIONAL AND PROFESSIONAL EXPERIENCE.

A. I hold a Bachelor of Arts degree in Environmental Science and Ecology from Brevard College. I also hold a Master of Science in Environmental Toxicology from Baylor University. I have 20 years of experience in surface water quality and regulations, environmental toxicology, hydrology, and ecological risk assessment. Much of my professional experience has focused on the development of site-specific water quality criteria for metals for the protection of aquatic life. My current projects include development of site-specific water quality criteria, ecological risk assessments, aquatic biological assessments, and hydrological assessments. Prior to forming Benchmark, I was an environmental consultant at Arcadis, U.S. from 2009-2017. From 2006-2009, I was a research scientist at Baylor University's Center for Reservoir and Aquatic Systems Research Center. From 2004-2005, I was a Biology and Environmental Science laboratory instructor at Brevard College. My résumé is attached to Petitioners' Notice of Intent to Present Technical Testimony as **Petitioners' Exhibit 6**.

Q. HAVE YOU PREVIOUSLY TESTIFIED BEFORE THE WATER QUALITY CONTROL COMMISSION ON SURFACE WATER QUALITY-RELATED ISSUES?

A. Yes, I testified before the New Mexico Water Quality Control Commission ("WQCC") during the 2015 Triennial Review regarding site-specific copper criteria and hydrology-based use-attainability analyses. I also testified before the WQCC during the 2020 Triennial Review regarding updates to New Mexico water quality standards.

Q. DO YOU HAVE OTHER EXPERIENCE RELVANT TO THIS PROCEEDING?

A. Yes. I have presented and participated in rulemaking proceedings in other jurisdictions for the adoption of site-specific water quality criteria. I also have extensive experience implementing the Environmental Protection Agency's ("EPA") copper biotic ligand model ("BLM"), which is the basis of the current proposal as discussed below, at other sites across the western U.S.

Q. ARE YOU SPONSORING ANY EXHIBITS?

A. Yes, throughout my testimony, I reference technical and regulatory information presented in the *Copper Site-Specific Water Quality Criteria for the Pajarito Plateau: Demonstration Report* ("Demonstration Report"), provided as **Petitioners' Exhibit 1**.

II. PURPOSE OF TESTIMONY

Q. WHAT IS THE PURPOSE OF YOUR TESTIMONY?

A. The purpose of my testimony is to provide the technical and regulatory bases for Petitioners' proposed amendments to the WQCC's Standards for Interstate and Intrastate Surface Waters, 20.6.4 NMAC ("Standards" or "Part 4") to add site-specific water quality criteria ("SSWQC") for copper proposed for surface waters within the geographic area referred to as the Pajarito Plateau. I have organized this testimony into the following four sections:

1) Overview of EPA and New Mexico aquatic life water quality criteria for copper as context for Petitioners' proposal;

(2) Development of the proposed SSWQC and explanation of how the proposed standard is consistent with the WQCC's regulations for Site Specific Standards;

3) Evaluation of data on the bioavailability and toxicity of copper that validates the proposed SSWQC; and

4) Recommendations on geographic area and surface waters for which copper SSWQC are proposed.

III. PROPOSED REGULATORY CHANGE

Q. PLEASE GENERALLY DESCRIBE PETITIONERS' PROPOSED RULE AMENDMENT.

A. The Petitioners are proposing amendments to 20.6.4.900 NMAC to incorporate copper SSWQC for surface water within or near the vicinity of Los Alamos National Laboratory ("Laboratory") in a geographic region known as the Pajarito Plateau. The proposed copper SSWQC were developed in accordance with procedures set forth in 20.6.4.10 NMAC for developing site-specific criteria and EPA's current recommended copper criteria for aquatic life.

Q. PLEASE SUMMARIZE THE RATIONALE FOR PROPOSING COPPER SSWQC.

A. New Mexico's current statewide copper criteria for aquatic life are based on EPA guidance published in 1996, which only account for the effect of water hardness on the bioavailability and toxicity of copper. In 2007, EPA published updated guidance for aquatic life copper criteria that incorporates new data on the toxicity of copper and uses the BLM, a metal bioavailability model. The BLM accounts for the effects of multiple water chemistry parameters on the bioavailability and toxicity of copper to aquatic life. BLM-based copper criteria incorporate the latest scientific information and provide improved guidance on the concentration of copper that will be protective of aquatic life.

BLM parameters[1] were monitored in Pajarito Plateau streams under EPA and NMED programs from 2005 to 2019, resulting in an extensive site-specific dataset for evaluating and adopting BLM-based criteria on a site-specific basis per procedures in 20.6.4.10 NMAC. The copper SSWQC proposed for Pajarito Plateau surface waters were developed as equations that replicate BLM-based copper criteria using three input parameters: dissolved organic carbon ("DOC"), pH, and hardness. As I discuss below, these equations were demonstrated to provide accurate and scientifically defensible calculations of BLM-based copper criteria which, if adopted by the WQCC, will provide a more accurate assessment of copper conditions for aquatic life uses in Pajarito Plateau surface water that can be used: (1) for National Pollutant Discharge Elimination System ("NPDES") permitting; (2) for Clean Water Act ("CWA") Section 303(d)/305(b) Integrated Assessments; and (3) to provide more accurate assessments of the protectiveness of copper conditions to aquatic life uses in Pajarito Plateau surface waters.

Q. WHAT WAS YOUR ROLE IN DEVELOPING THE PROPOSED COPPER SSWQC

A. Petitioners retained Windward in 2016 to provide technical support for LANL's stormwater individual permit ("IP"), including the development of SSWQC and design and implementation of surface water monitoring programs for collection of BLM water quality

[1] The copper BLM utilizes 12 input parameters to calculate BLM-based copper criteria: temperature, pH, dissolved organic carbon, percent humic acid (% HA), major cations (calcium, magnesium, sodium, and potassium), major anions (sulfate and chloride), alkalinity, and sulfide. However, two parameters, % HA and sulfide, are not required to calculate BLM-based copper criteria. Because % HA is rarely measured in ambient waters, EPA recommends a default value of 10% HA. Sulfide does not affect BLM-based copper criteria; however, EPA recommends a small non-zero value for BLM calculations. Consequently, 10 water chemistry parameters are needed to run the BLM model for copper.

parameters. Windward subsequently was retained by N3B to develop the Demonstration Report, which provides the regulatory background and technical information that supports the proposed copper SSWQC. I began working with Windward and N3B on copper BLM evaluations and the development of copper SSWQC for the Pajarito Plateau in 2019. My specific roles have included authorship of the work plan (**Petitioners' Exhibit 9**), Demonstration Report (**Petitioners' Exhibit 1**), and presentations to stakeholders and the public as summarized in the direct testimony provided by Dr. Amanda White.

Q. DOES PETITIONERS' PROPOSAL RELY ON A SCIENTIFICALLY DEFENSIBLE METHOD?

A. Yes. The copper SSWQC replicate the results of the copper BLM, which is the basis of EPA's current recommended aquatic life criteria for copper. This is explained in more detail later in my testimony.

Q. DOES THE PROPOSED COPPER SSWQC PROTECT THE APPLICABLE DESIGNATED USE TO WHICH IT WILL APPLY?

A. Yes. EPA concluded that BLM criteria will more accurately yield the level of protection intended to protect and maintain aquatic life uses. NMED also recognized the BLM provides a more accurate assessment of copper bioavailability. Because the proposed copper SSWQC equations replicate EPA's 2007 BLM criteria with a high degree of accuracy over the range of site-specific conditions monitored in Pajarito Plateau surface waters, they will fully protect aquatic life uses consistent with current EPA recommendations.

Q. WHY ARE PETITIONERS PROPOSING THIS CHANGE OUTSIDE OF A TRIENNIAL REVIEW?

A. NMED explained in the last Triennial Review proceeding (WQCC No. 20-51(R)) that it did not have adequate information to support adoption of EPA's recommended aquatic life criteria for copper as a replacement of the WQCC's hardness-based copper criteria. However, consistent with the recommendation from EPA, NMED stated that it would continue to evaluate the implementation of the BLM for copper on a segment-specific basis (WQCC No. 20-51(R), Direct Technical Testimony of Kris Barrios (NMED Ex. 2) at 14 **provided as Petitioners' Exhibit 12**). As I explain below, surface waters on the Pajarito Plateau have been extensively monitored for the parameters necessary for calculating EPA's recommended aquatic life criteria. Therefore, it is a suitable setting for adopting the updated EPA copper criteria on a segment-specific basis, consistent with EPA recommendations and NMED's explanation for adopting the updated EPA copper criteria for New Mexico surface waters.

IV. BACKGROUND ON EPA AND WQCC CRITERIA FOR COPPER

Q. PLEASE DESCRIBE EPA'S AQUATIC LIFE WATER QUALITY CRITERIA FOR COPPER.

A. Section 304(a)(1) of the CWA requires EPA to develop and publish criteria for the protection of water quality and periodically revise the water quality criteria to reflect the latest scientific knowledge. Early criteria for copper published in 1984 and updated in 1996 were developed to take into account the effects of ambient hardness on copper toxicity to aquatic life ("hardness-based copper criteria"). In 2007, EPA updated its national recommended CWA Section 304(a) criteria for copper to reflect the latest available scientific information on the bioavailability and toxicity of copper (EPA 2007 copper criteria are provided in **Petitioners' Exhibit 10**). The EPA 2007 copper criteria utilize a more advanced modeling approach for developing water quality criteria called the copper BLM. The copper BLM is a bioavailability software model that incorporates multiple water chemistry parameters to calculate copper bioavailability and criteria. Compared to the EPA (1996) hardness-based copper criteria (**Petitioners' Exhibit 11**), the EPA 2007 copper BLM provides improved guidance on the concentrations of copper that will be protective of aquatic life because it incorporates additional water chemistry parameters that affect the bioavailability and toxicity of copper to aquatic life (EPA 2007).

Q. WHAT ARE THE CURRENT STATEWIDE AQUATIC LIFE WATER QUALITY CRITERIA FOR COPPER?

A. The current statewide copper criteria for protection of aquatic life in New Mexico surface waters (20.6.4.900.I NMAC) are based on EPA's CWA Section 304(a) guidance published in 1996 (**Petitioners' Exhibit 11**). The EPA 1996 copper criteria are referred to as hardness-based criteria because they are based on an empirical relationship between toxicity and water hardness (water hardness is the concentration of dissolved calcium and magnesium). These hardness-based copper criteria are expressed as regression equations, which calculate copper criteria values as a function of water hardness. The hardness-based criteria values increase with increasing concentrations of water hardness due to the protective effect of hardness on copper toxicity.

The hardness-based equation to calculate acute copper criteria (in µg/L as dissolved copper) is:

Acute Copper Criteria = exp(0.9422)[ln(hardness)]-1.700) x (0.96)

The hardness-based equation to calculate chronic copper criteria (in µg/L as dissolved copper) is:

Chronic Copper Criteria = exp(0.8545)[ln(hardness)]-1.702) x (0.96)

The following table shows examples of hardness-based copper criteria values over a range of hardness concentrations.

Hardness as CaCO3, dissolved (mg/L)	Acute or Chronic	Copper Criteria (µg/L)
25	Acute	3.64
	Chronic	2.74
50	Acute	6.99
	Chronic	4.95
100	Acute	13.4
	Chronic	8.96
200	Acute	25.8
	Chronic	16.2
300	Acute	37.8
	Chronic	22.9
400 and above	Acute	49.6
	Chronic	29.3

In the last Triennial Review rulemaking proceeding, NMED proposed to retain New Mexico’s hardness-based numeric water quality criteria instead of adopting EPA’s BLM-based copper criteria. While NMED agreed that the BLM provides a more accurate assessment of copper bioavailability than the WQCC’s hardness-based copper criteria, NMED did not have sufficient data to support statewide implementation of EPA’s 2007 CWA Section 304(a) recommended aquatic life criteria for copper. NMED stated in testimony that per EPA’s recommendation, it would continue to evaluate the implementation of EPA's BLM-based criteria for copper on a segment-specific basis **Petitioners' Exhibit 12** (WQCC No. 20-51(R), Direct Technical Testimony of Kris Barrios (NMED Ex. 2) at 14).

V. DEVELOPMENT OF COPPER SSWQC FOR THEPAJARITO PLATEAU SURFACE WATERS

Q. PLEASE DESCRIBE EPA'S COPPER BLM INPUTS AND FUNCTIONS

A. The copper BLM computes acute and chronic criteria based on inputs of 12 water chemistry parameters. However, many input parameters have little or no effect on the bioavailability or toxicity of copper, and thus, on the magnitude of the resulting BLM criteria. The three parameters shown to have the strongest impact on copper bioavailability are DOC, pH, and hardness. A schematic that depicts the mechanisms by which these three parameters affect copper bioavailability is provided in **Petitioners' Exhibit 1** and summarized as follows:

- DOC: refers to organic carbon dissolved in water that is impermeable to biological membranes. DOC forms chemical complexes with copper that reduce its bioavailability.
- pH: affects copper bioavailability via speciation, solubility, and competitive interactions. Copper toxicity and pH are inversely related because free copper (Cu^{2+}), which is the toxic form of copper, is more present at lower pH levels. As pH increases, Cu^{2+} decreases due to complexation with carbonates and hydroxides.
- Hardness: refers to concentrations of calcium ("Ca") and magnesium ("Mg") ions in freshwater systems. Increased hardness decreases toxicity due to Ca and Mg occupying binding sites on biological tissues, thereby reducing uptake of copper into the organism.

Q. HAVE PETITIONERS SAMPLED BLM PARAMETERS IN PAJARITO PLATEAU?

Yes. Dr. White testifies that BLM parameters have been sampled in Pajarito Plateau streams since 2005 and addresses the collection of data to support this proposal. The final copper BLM dataset included 517 discrete surface water samples collected from 2005 to 2019 in eight sub-watersheds on the Pajarito Plateau. The final dataset is provided in **Appendix A of Petitioners' Exhibit 1; Petitioners' Exhibit 1** also presents a map that depicts the surface water sample locations, along with tables and figures that summarize the distribution of copper BLM samples by watershed and over time.

A data quality objective / data quality assessment (DQO/DQA) process was applied to develop an appropriate copper BLM dataset for calculating copper BLM criteria consistent with EPA guidance. Section 5.1 of the Demonstration Report (**Petitioners' Exhibit 1**) summarizes the DQO/DQA process; the Windward (2018) DQO/DQA report for developing a site-specific BLM dataset is provided as **Petitioners' Exhibit 14**.

The dataset was analyzed for water quality parameters necessary for calculating copper criteria using the copper BLM software (version 3.41.2.45) in accordance with EPA guidance. A summary of the 517 surface water samples is provided in Section 5.1 of the Demonstration Report (**Petitioners' Exhibit 1**).

Q. PLEASE DESCRIBE HOW YOU USED THIS SAMPLING DATA TO DEVELOP THE PROPOSED COPPER SSWQC.

A. The 517 samples collected from Pajarito Plateau surface waters with sufficient BLM water chemistry data were input into the BLM software to generate acute and chronic BLM-based criteria. Statistical analyses were conducted between water chemistry parameters (i.e., copper BLM input parameters) and copper BLM criteria values (i.e., copper BLM output values) to determine water chemistry parameters most influential on copper BLM criteria values on a site-specific basis.

Q. WHAT DID THE STATISTICAL EVALUATIONS DEMONSTRATE?

A. This evaluation demonstrated that DOC, pH, and hardness control BLM-based criteria values across the range of site-specific water chemistries observed on the Pajarito Plateau.

Q. PLEASE DESCRIBE THE PROCESS USED TO DEVELOP THE COPPER SSWQC PROPOSED HERE.

A. Multiple linear regression (MLR) equations were developed that utilize DOC, pH, and hardness to calculate BLM-based criteria, which are the equations proposed for the copper SSWQC as provided below:

Acute copper SSWQC = exp (-22.914 + 1.017 x ln(DOC) + 0.045 x ln(hardness) + 5.176 x pH – 0.261 x pH^2)

Chronic copper SSWQC = exp (-23.391 + 1.017 x ln(DOC) + 0.045 x ln(hardness) + 5.176 x pH – 0.261 x pH^2)d

Q. ARE THE PROPOSED MLR EQUATIONS CONSISTENT WITH THE COMMISSION'S APPROVED SCIENTIFICALLY DEFENSIBLE METHODS IDENTIFIED IN 20.6.4.10(F)(4)(C) NMAC?

A. Yes. Although New Mexico has not adopted the BLM-based copper criteria as statewide criteria, as EPA recommended, New Mexico identifies the BLM as a scientifically defensible method for developing site-specific copper criteria in 20.6.4.10(F)(4)(c) NMAC. The provisions in 20.6.4.10(F)(1) NMAC describe relevant conditions for developing site-specific criteria, one of which includes "physical or chemical characteristics at a site such as pH or hardness alter the biological availability and/or toxicity of the chemical." The copper BLM is a scientifically defensible method recommended by EPA and accepted by the WQCC (on a site-specific basis) that explicitly considers the effects of multiple water chemistry parameters on copper bioavailability and toxicity.

The copper SSWQC proposed for Pajarito Plateau surface waters are expressed as MLR equations that accurately calculate EPA's (2007) BLM-based copper criteria. The MLR equations are similar to the simple linear regression equations that are the hardness-based criteria, but the MLR equations take into account the effects of DOC, pH, and hardness on copper bioavailability and toxicity. As I discuss below, use of MLR equations is also a scientifically defensible method for calculating water quality criteria.

Q. DID YOU VERIFY THE ACCURACY WITH WHICH THE MLR EQUATIONS CALCULATE COPPER BLM CRITERIA?

A. Yes. The proposed MLR equations accounted for 98% of the variation observed in BLM-based criteria values, indicating the MLR equations are highly accurate in calculating BLM-based copper criteria across the range of site-specific conditions observed on the Pajarito Plateau. Additional evaluations further demonstrated the accuracy with which the MLR equations calculate BLM-based copper criteria at different ranges and combinations of DOC, pH, and hardness that are representative of conditions observed in Pajarito Plateau surface waters (Section 5.4.2 of the Demonstration Report provided as **Petitioners' Exhibit 1**). The high degree of consistency between the copper SSWQC calculated via the MLR equations versus the copper criteria calculated via the copper BLM software indicates that the proposed copper SSWQC equations provide a reliable and scientifically defensible method to calculate EPA's (2007) nationally recommended copper criteria on a site-specific basis.

Q. IS THERE A PRECEDENT FOR EXRESSING WATER QUALITY CRITERIA AS MLR EQUATIONS?

A. Yes. EPA's current CWA Section 304(a) guidance utilize MLR equations to calculate: (1) aluminum criteria values as a function a DOC, pH, and hardness; and (2) ammonia criteria values as a function of pH and water temperature. EPA also has approved MLR equations that accurately calculate BLM-based copper criteria on a site-specific basis (see **Petitioners' Exhibit 14**). In addition, EPA has identified MLR equations as a scientifically defensible approach to calculate aquatic life criteria for multiple metals. For copper specifically, EPA found that MLR equations can calculate copper criteria for the protection of aquatic life with the same degree of accuracy as the copper BLM software (**Section 4.3 of the Demonstration Report, Petitioners' Ex 1**).

Q. ARE THERE ADVANTAGES OF EXPRESSING THE PROPOSED COPPER SSWQC IN EQUATION FORMAT RATHER THAN BLM SOFTWARE FORMAT?

A. There are at least four advantages of expressing the copper SSWQC as equations rather than BLM software format: (1) the proposed SSWQC equations can be readily incorporated into New Mexico's water quality standards in a transparent equation format similar to criteria for other constituents; (2) special training or access to the copper BLM software is not required; (3) potential issues with BLM software versions are avoided; and (4) monitoring and assessment of the copper criteria would be streamlined because the equations require only three input parameters, rather than the 12 input parameters needed to calculate copper criteria using the BLM software.

VI. PROPOSED APPLICATION OF THE COPPER SSWQC

Q. PLEASE DESCRIBE THE SPECIFIC WATERS TO WHICH THE COPPER SSWQC WOULD APPLY.

A. The spatial boundaries and specific waters to which the proposed copper SSWQC would apply include all watersheds within the area of the Pajarito Plateau as depicted on Map 6-1 in the Demonstration Report (**Petitioners' Exhibit 1**). This area includes from the Guaje Canyon watershed in the north to El Rito de Frijoles in the south, from their headwaters to their confluence with the Rio Grande and all tributaries and streams thereto. This area for the proposed SSWQC corresponds to surface water locations on the Pajarito Plateau in the vicinity of LANL that contained sufficient BLM datasets and were included in the development and validation of the proposed copper SSWQC equations.

Q. WHAT IS THE JUSTIFICATION FOR MODIFYING THE DEFAULT CRITERIA?

A. New Mexico's statewide hardness-based criteria do not account for water chemistry parameters other than hardness. However, the water chemistry parameters of DOC and pH also naturally vary across ambient surface waters and impact the bioavailability and toxicity of copper. These parameters have been sufficiently measured throughout Pajarito Plateau surface waters, making it a suitable setting for the adoption of the proposed copper SSWQC that more accurately yield the level of protection intended to protect and maintain aquatic life uses than the hardness-based copper criteria.

Q. WHAT ARE THE DESIGNATED USES TO WHICH THIS COPPER SSWQC WOULD APPLY?

A. The proposed copper SSWQC would apply to all aquatic life uses designated for Pajarito Plateau streams.

As explained by Dr. White, most waterbodies within the Pajarito Plateau are classified as ephemeral or intermittent (20.6.4.128 NMAC) and are therefore designated as providing a limited aquatic life use and subject to acute criteria only. For these waters, the acute copper SSWQC equations would be applied to protect the designated aquatic life use.

Other water bodies within the Pajarito Plateau are classified as perennial (20.6.4.126 and 20.6.4.121 NMAC) and are designated as providing higher-level aquatic life uses that are subject to both acute and chronic aquatic life criteria. Unclassified intermittent surface water segments classified at 20.6.4.98 NMAC and other intermittent waters classified at 20.6.4.140 NMAC are designated as marginal warm water aquatic life use and are also subject to both acute and chronic aquatic life criteria. Therefore, the acute and chronic copper SSWQC equations would apply to these waters of the Pajarito Plateau as well.

Q. DOES THE PROPOSED CRITERIA FULLY PROTECT THAT DESIGNATED USE?

A. Yes, for the reasons described in my testimony, the proposed copper SSWQC provide accurate calculations of EPA's copper BLM and thus will fully protect aquatic life uses. The proposed SSWQC are based on EPA's current recommended copper criteria and incorporate the best available scientific information regarding the bioavailability and toxicity of copper to aquatic life. Therefore, the proposed SSWQC will provide the level of protection intended to protect and maintain aquatic life uses better than the hardness-based copper criteria.

VII. CONCLUSION

Q. PLEASE SUMMARIZE YOUR RECOMMENDATION TO THE COMMISSION.

A. I recommend the Commission adopt Petitioners' proposed copper SSWQC for Pajarito Plateau surface waters. As addressed in my testimony, the proposed copper SSWQC were developed based on EPA's current recommendations and in accordance with WQCC procedures for developing site-specific criteria. Adopting the proposed copper SSWQC will yield more accurate criteria for the protection of aquatic life uses and, therefore, will improve site-specific assessments of copper in Pajarito Plateau surface waters.

Q. DOES THIS CONCLUDE YOUR DIRECT TESTIMONY?

A. Yes.

Amanda B. White

Experience

DIRECTOR | SEALASKA | JULY 2023-PRESENT

- Senior executive manager leading the Tech2 Solutions critical water program subcontract under DOE-EM's Los Alamos Legacy Cleanup Contract.
- Safely lead a team of over 75 environmental professionals, scientists, engineers, GIS specialists, field samplers, and drilling experts, and manage an EVMS-compliant performance baseline.
- Plan and execute technical scope, including environmental water well drilling in support of the chromium plume interim measure clean up, and site-wide groundwater and surface water monitoring in support of the DOE Consent Order.
- Interface with prime contractor N3B, EM-LA, tribal nations, and state and county regulatory stakeholders on environmental and regulatory compliance, quality assurance, and engineering standards.

DEPUTY DIRECTOR | TETRA TECH | JANUARY 2022-JULY 2023

- Senior leader providing overall program management and team leadership for over 40 people in a joint venture project under DOE-EM's Los Alamos Legacy Cleanup Contract.
- Interface with DOE, contractors, tribal nations, and state and county regulatory stakeholders on environmental and regulatory compliance, quality assurance, and engineering standards.
- Safely and compliantly planned performance management baseline and participated in successful self-certification of Earned-Value Management System (EVMS), including develop and maintain risk register, plan baseline costs and schedules, and prepare detailed basis of estimates (BOEs).
- Perform Management Observations (MOVs) in the field and office in support of continuous improvement, safety, and quality initiatives.
- Develop and ensure closure of corrective actions in the Contractor Assurance System (CAS) in support of DOE Order 226.1B.

WATERSHED MONITORING AND TECHNICAL SERVICES PROGRAM MANAGER | TETRA TECH | NOVEMBER 2020-JANUARY 2022

- Managed the Individual Permit Monitoring and Corrective Actions Program, Surface Water and Sediment Monitoring Program, Storm Water Processing Facility, and Technical Services consisting of GIS, Engineering, and Telemetry Teams.
- Managed four Project Managers, each of whom have 6-7 staff members, including mentorship, identifying and addressing staff needs, conducting team meetings, developing staffing plans, conducting performance appraisals, etc.
- Responsible for a myriad of deliverables to the NMED, EPA, and DOE.
- Interfaced and negotiated with various stakeholders, including state and federal regulators and environmental activists, to determine the best path forward for all parties.
- Led efforts regarding the Settlement Agreement with the New Mexico Environment Department for the State Certification of the Individual Permit, including legal counsel, DOE, and regulator interfacing and negotiations.

PETITIONERS' EXHIBIT 5

- Led efforts regarding the Copper Site-Specific Water Quality Criteria, including legal counsel, DOE, and regulator interfacing, stakeholder involvement, and preparing for the petition to the Water Quality Control Commission.
- Planned for the future by staying informed on up-and-coming changes to state and federal surface water regulations, water quality criteria, and contaminants of emerging concern such as PFAS.
- Continuously brainstormed, developed, and implemented process improvements with time and cost consciousness at the core.
- Served as the Control Account Manager (CAM) for 6 control accounts.
- Managed the budget and schedule, including: writing monthly variance reports, preparing monthly status of projects, updating estimates to complete monthly, preparing monthly accruals, approving procurement requests and invoices, ensuring staff are charging to the correct projects, preparing baseline change proposals and revising the baseline if necessary, updating technical support documents and basis of estimates, and updating the risk register.
- Managed several subcontracts, including both firm fixed price and time and materials contracts.

SURFACE WATER PROJECT MANAGER | TETRA TECH | APRIL 2018-OCTOBER 2020

- Managed the following projects: Individual Permit Monitoring and Corrective Actions Project, Los Alamos/Pueblo Watershed Monitoring Project, Sandia Wetland Performance Monitoring Project, City of Santa Fe's Buckman Direct Diversion Early Notification System, Gaging Station Monitoring Project, and Annual Lab-Wide Sediment Sampling Campaign.
- Managed the Laboratory's network of 50 streamflow and 15 precipitation gaging stations, including field operations and data management.
- Managed the Laboratory's network of 250 IP Site Monitoring Areas (SMAs) and 2000+ IP BMPs, including field operations and data management.
- Managed 7-12 staff members, including mentorship, identifying staff needs, conducting weekly team meetings, developing staffing plans, conducting performance appraisals, etc.
- Was responsible for a myriad of deliverables to the NMED, EPA, and DOE driven by the 2016 NMED Order of Consent, the 2010 Individual Permit, DOE Order 231.1B Environment, Safety and Health Reporting, and DOE Order 458.1 Radiation Protection of the Public and the Environment.
- Developed and managed the 9-year baseline budget and schedule, including development of the work breakdown structure (WBS), preparation of technical support documents (TSDs) and basis of estimates (BOEs), development of and updating the risk register.
- Interfaced with subcontractors to determine staffing plans, goals, SOPs, IWCPs, and training matrices.
- Managed yellow iron subcontracts for enhanced control structures, including RFP preparation, bid review, and contract award.
- Prepared and manage sample analysis plans for storm water, surface water, and sediment sampling.
- Managed the storm water processing facility with respect to RCRA/DOE waste management, OSHA compliance, and internal environmental, safety, health, and quality assurance standards.
- Interfaced with various stakeholders, including state and federal regulators and environmental activists.

HYDROLOGIST | LOS ALAMOS NATIONAL LABORATORY | 2010-APRIL 2018

- Supervised the data management, operation, and maintenance of the Laboratory's discharge and precipitation gaging station network.

- Performed NMED-, EPA-, and DOE-driven sampling campaigns for stormwater and sediment media, including preparing sampling plans, organizing fieldwork, and performing data analyses.
- Lead author of reports required by the NMED, EPA, and DOE on water quality, water quantity, and sediment transport throughout the Laboratory.
- Managed 3 GIS analysts and their workloads, including maintaining the GIS database.
- Managed Santa Fe's Buckman Direct Diversion Early Notification System.
- Assisted with the Laboratory's NPDES Individual Permit (IP) for stormwater monitoring.

RESEARCH ASSOCIATE | NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY | 2009-2010

- Researched the hydrology of snow-dominated, topographically-complex mountains of Northern New Mexico (Rio Jemez, Rio Hondo, and El Rito River Basins) and the impacts of climate change on water resources using USGS's Precipitation-Runoff Modeling System (PRMS).
- Guest lecturer in various classes, including Surface Water Modeling and Climate Change Impacts.

POSTDOCTORAL ASSOCIATE | LOS ALAMOS NATIONAL LABORATORY | 2006-2009

- Investigated the dynamics associated with large-scale, southwestern U.S. piñon mortality in order to gain a greater understanding of the non-linear, cross-scale influence of global-change-type drought, temperature changes, and bark beetle dynamics on tree mortality.
- Examined the influences of vegetation change due to piñon mortality on the water budget in the Rio Chama Basin via a physically-based, distributed hydrologic model, tRIBS.

ADJUNCT PROFESSOR | UNIVERSITY OF NEW MEXICO | SPRING 2009

- Developed and taught two introductory classes, GIS and soil science.
- Goals of the Introduction to GIS class were to familiarize students with ArcMap, cartographic principles, and relational databases, and to assist students in exploring and analyzing spatial, environmental datasets and problems.
- Goals of the Introduction to Soils class were to acquaint students with soil formation, taxonomy, physical properties, texture, and structure, and the behavior and characteristics of water in soil.

PH.D. CANDIDATE | UNIVERSITY OF ILLINOIS | 2001-2006

- Investigated variability of vegetation and its dependence on hydroclimatology, including topography, large-scale climate pattern, precipitation, air temperature, incident radiation, soil properties, land cover, and ecology.
- Developed and employed spatio-temporal data mining techniques to achieve this goal.

TEACHING ASSISTANT | UNIVERSITY OF ILLINOIS | 2000-2003

- Developed ArcView exercises to familiarize students with the ArcView software, expose the students to various spatial datasets, including soil type, land use, precipitation, DEMs, and river network data, allow students to qualitatively and quantitatively analyze the datasets, and assist the students in importing relevant data into and implementing a hydrologic model, HEC-HMS.
- Taught the computer lab portion of the associated class, Hydrologic Modeling, during which the students implemented the ArcView exercises.

M.S. CANDIDATE | UNIVERSITY OF ILLINOIS | 1999-2001

- Investigated processes that contribute to variance of the network hydrologic response.
- Compared geomorphologic and hydrodynamic dispersion coefficients at different scales.
- Determined the impacts of anthropogenic modifications of stream networks on river basin response.

ENVIRONMENTAL ENGINEER | GANNETT FLEMING | 1997-2000

- Managed (scheduled, planning, and budgeting) various projects, including the City of Hampton's stormwater management program to prevent flooding, various military bases' stormwater pollution prevention programs, and remediation efforts at a U.S. EPA Superfund location.
- Undertook a wide variety of projects, including assisting with the design of a water distribution main for the Washington D.C. area, design of a stormwater detention basin with a wetlands filtration system, and hydraulic and hydrologic modeling of the City of Newport News' stormwater system.

Education

PH.D. | 2006 | UNIVERSITY OF ILLINOIS

- Major: Civil and Environmental Engineering
- Minor: Computational Science and Engineering
- Thesis: Vegetation Variability and its Hydro-Climatologic Dependence

M.S. | 2001 | UNIVERSITY OF ILLINOIS

- Major: Civil and Environmental Engineering
- Thesis: Hydrodynamic and Geomorphologic Dispersion: Scale Effects in the Illinois River Basin

B.S. | 1997 | OLD DOMINION UNIVERSITY

- Major: Civil Engineering
- Thesis: Wetland Design for Filtration of Urban Stormwater Runoff

Awards & Affiliations

AWARDS AND RECOGNITIONS

- Institute of Geophysics and Planetary Physics Fellowship, 2006, "Impacts of Extreme Climatologic Events on Environmental Infrastructure," Los Alamos National Laboratory
- Glenn and Helen Stout Water Resources Research Award, 2004, for "Academic Achievement and Outstanding Research in Water Resources," Civil and Environmental Engineering Department, University of Illinois at Urbana-Champaign
- NASA Earth Systems Science Fellowship, 2000, "Knowledge Discovery from Remote Sensing Observations"
- Magna cum Laude, Bachelor of Science, 1997, Old Dominion University
- Dean's List, Bachelor of Science, 1993-1997, Old Dominion University
- Norfolk School Board Scholarship, 1993-1995, Old Dominion University

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Barry Fulton

Principal Scientist / Owner

Summary of Expertise

Mr. Fulton is a scientist with 20 years of research and consulting experience. His core areas of expertise are surface water quality and regulations, environmental toxicology, hydrology, and ecological risk assessment. He has served as project manager, program manager, and technical expert on mining, municipal and industrial projects under various state and federal regulatory programs.

Much of Mr. Fulton's experience relates to various aspects of water quality criteria and environmental assessments. In particular, he has developed site-specific water quality criteria (SSWQC) for metals at multiple sites across the western U.S. and provided expert testimony in multiple jurisdictions to support rulemakings on water quality standards and regulations.

As the principal scientist and owner of Benchmark Environmental LLC (Benchmark), he provides technical and strategic support to clients for management of environmental risks posed by contaminated sites and pollutant releases. He has conducted ecological risk assessments, natural resource damage assessments, long-term biological monitoring and assessments for benthic macroinvertebrates and fish, and aquatic toxicity and bioaccumulation studies.

Prior to forming Benchmark Environmental LLC, Mr. Fulton worked for ten years as an environmental consultant at Arcadis U.S., Inc where he served as a principal scientist and technical expert on a wide range of projects related to surface water quality and regulations, and routinely led engagements with agencies and stakeholders. His core projects at Arcadis included: development of site-specific water quality criteria, technical impracticability waivers for surface water standards, NPDES permitting, Use-Attainability Analyses, and large-scale ecological risk assessments for aquatic and terrestrial resources.

Prior to Arcadis, Mr. Fulton worked as a research scientist at Baylor University's Center for Reservoir and Aquatic Systems Research. He conducted field research on streams, lakes, and reservoirs; performed analytical chemistry; and managed laboratory aquatic toxicity studies.

Areas of Specialization

- Water quality regulations
- Aquatic life criteria
- Aquatic biological monitoring
- Site and hazard assessments
- Aquatic toxicology
- Analytical chemistry

Education

- M.S., Environmental Toxicology, Baylor University, 2008
- BS, Aquatic Ecology; BS, Environmental Science, Brevard College, 2005

Work History

- Principal Scientist / Owner, Benchmark Environmental LLC, 2017-present
- Environmental Toxicologist / Program Manager, Arcadis, Inc., 2009-2017
- Aquatic Biologist / Research Scientist, Center for Reservoir & Aquatic Systems Research, 2005-2008
- Aquatic Ecology Laboratory Instructor, Brevard College, 2004-2005

Memberships

- Society of Environmental Toxicology and Chemistry

Years of Experience

- 20 years

Sample Project Experience

Development of Site-Specific Aluminum, Copper, and Manganese Aquatic Life Criteria

Mining Client, Arizona, USA (2016-present)
Developing SSWQC for aluminum, copper, and manganese based on best available science to replace outdated Remedial Action Objectives. Ongoing work includes development and implementation of a surface water monitoring program, benthic macroinvertebrate assessments, laboratory toxicity studies, bioavailability models, and regulatory engagement to support SSWQC for these metals. Mr. Fulton is leading all aspects of field work, reporting, oversight to toxicity labs, and stakeholder engagement.

Development of Site-Specific Selenium Criteria

Clark County Regional Flood Control, Nevada, USA (2020-2024)
Developed SSWQC for selenium for the Las Vegas Wash Sub-basin including site-specific fish-tissue and water-column values. Mr. Fulton led all technical evaluations, regulatory engagement and rulemaking efforts with NDEP and USEPA and served as the testifying expert during rulemaking.

Comprehensive Watershed Management & Monitoring Plan

Mining Client, Montana, USA (2012-2024)
Technical lead on the development and implementation of a omprehensive, long-term surface water management and monitoring plan for a CERCLA site that spans multiple sub-basins in the upper Clark Fork River portion of the Columbia River basin, consisting of: (1) Technical Impracticability (TI) evaluations for surface water ARARs based on source, fate, and transport pathways, (2) site-specific toxicity, bioavailability, and uptake studies for aquatic life resources, (3) annual benthic macroinvertebrate community assessments and quantitative analyses to evaluate community structure and function across contaminant gradients in surface water, sediment, and tissues, accounting for physical habitat differences, (4) development of bioavailability-based site-specific ARARs, and (5) protectiveness evaluations of aquatic life resources for remedy performance monitoring, EPA 5-year reviews, and NRDA evaluations.

NRDA for Southeast Idaho Phosphate Mines

Mining Client, Idaho, USA (2016-2022)
Served as the technical expert on behalf of client for assessing potential injuries and damages to aquatic life resources due to selenium releases with a focus on salmonids and benthic macroinvertebrates. Presented to trustees on aquatic injury assessments and debit/credit analyses; facilitated and led weekly workshops with trustees' aquatic experts to develop injury assessment curves and debit calculations that incorporate salmonid life histories, modes of toxicity, physical habitat, and background levels.

Development of Site-Specific Aquatic Life Criteria for Metals and Expert Testimony

Los Alamos National Laboratory, NM, USA (2018-2024)
Serving as the technical lead and testifying expert on the development of copper site-specific criteria (SSC) for aquatic life for multiple watersheds affected by legacy contamination on the Pajarito Plateau. Developed multiple-linear regression equations for site-specific copper criteria

that incorporate key toxicity modifying factors using EPA's copper biotic ligand model and site-specific data.

Long-term Biological Monitoring and Bioavailability Studies

Mining Site, Arizona, USA

2020-2024

Lead investigator in planning, conducting, and reporting benthic macroinvertebrate community evaluations and site-specific toxicity testing to evaluate contaminant uptake and bioavailability. Benthic invertebrate sampling is conducted at locations that span potential mining impacts using different sampling methods (Hess, Kick-Nets) according to habitat characteristics. Taxonomy data are interpreted and reported relative to exposure concentrations, habitat conditions, and variance observed over the long-term monitoring period. In addition to quantitative benthic invertebrate community analyses, site-specific toxicity studies are supporting updates to remedial action objectives that account for contaminant bioavailability.

Development of Site-Specific Aquatic Life Criteria for Selenium

Mining Client, Idaho, USA (2015-2022)

Developed selenium SSC for aquatic life based on the most-sensitive resident salmonids in two subbasins affected by active and historical phosphate mines. Established list of resident fish species from comprehensive fishery studies; demonstrated protectiveness of the most-sensitive species approach by analyzing toxicity data from all resident fish species and showing that criteria based on the most sensitive resident fish species will protect other resident fish and aquatic taxa per EPA guidance; developed bioaccumulation models to translate fish-tissue criteria into water-column values; developed approach to address protectiveness of site-specific criteria to aquatic taxa in ephemeral and intermittent fishless drainages; and provided expert testimony during rulemaking.

Aquatic and Terrestrial Ecological Risk Assessments

Mining Client, Idaho, USA (2015-2023)

Technical lead on large-scale baseline ecological risk assessment for aquatic and terrestrial resources associated with legacy phosphate mines. Conducted exposure and effects estimates, chemical speciation studies, developed toxicity reference values, and co-authored baseline ecological risk assessments for two adjacent mine sites, comprising pit lakes, springs, streams and sagebrush uplands.

Use-Attainability Analyses

Clark County Regional Flood Control, Nevada, USA (2020-2023)

Conducted UAAs across a large, urbanized watershed to re-designate tributaries and storm-water conveyances to reflect attainable uses and corresponding aquatic life, human health, and agricultural water quality standards.

Rulemaking for Arsenic Human Health Criteria

Mining Client, Idaho, USA (2019-2023)

Negotiated rulemaking to support DEQ's revisions to arsenic human health criteria for primary and secondary contact recreation uses.

Pit Lake Risk Assessment and Remedial Investigation

Mining Client, Idaho (2014-2022)

Technical lead on the ecological risk assessment for large pit lakes associated with legacy phosphate mines. Successfully demonstrated no unacceptable risk to aquatic and terrestrial resources, avoiding further RI/FS efforts. Co-authored baseline ERA report and led discussions with state and federal agencies.

Remedial Investigation/Feasibility Study

Mining Client, Idaho (2014-present)

Key team member and technical expert to support RI/FS evaluations for a large-scale phosphate mine with perennial streams that support salmonid spawning and non-perennial, fishless tributaries. Designed field studies to evaluate fate and transport of metals and metalloids.

Stream Bioassessments for Narrative Criteria

Mining Client, Arizona (2020-present)

In 2020, Mr. Fulton became the lead investigator of a long-term (20-yr) bioassessment program to demonstrate the protectiveness of mine operations to downstream aquatic communities and attainment of narrative water quality standards (e.g., bio-criteria). He leads all aspects of field work, analyses, and regulatory engagement.

Reasonable Potential Analyses

Mining Client, Montana (2019-present)

Performed RP analyses on radionuclides for permitted discharges to support revisions to ongoing monitoring and reporting under CERCLA.

Metal Translator Study and Use-Attainability Analysis

Mining Client, Nevada, USA (2019-present)

Conducted a site-specific metals translator study to convert state water quality standards from dissolved to total recoverable metal limits in an NPDES permit. Given the low frequency at which the facility discharges, receiving water and effluents are mixed to simulate a range of conditions determined from hydrological and chemical modeling. In addition, Mr. Fulton is conducting a UAA to support re-designations based on existing aquatic life uses and developing study plans to conduct site-specific toxicity tests to support application of the biotic ligand model.

Water Quality and Aquatic Toxicity Evaluations

Mining Client, Colorado, USA (2018-2022)

Technical lead on water quality and aquatic toxicity studies to demonstrate the performance of a passive, flow-through treatment system. Conducted toxicity evaluations to determine sources of fish lethality and developed site-specific benchmarks for metals.

Weight of Evidence Sediment Assessment

Mining Client, Montana, USA (2019-present)

Mr. Fulton developed a WOE framework to address removal criteria for contaminated stream sediment at a legacy mine site, comprised of benthic macroinvertebrate assessments, sediment assays, and sediment and surface-water bioavailability studies.

Site-Specific Discharge Limits for Calcium and Sulfate

Mining Client, Montana, USA (2017-present)

Mr. Fulton developed a WET testing program and designed TIE/TRE studies for treated effluent from a tailings impoundment at a historic mining site. After demonstrating that calcium and sulfate are the primary toxicants, he developed a WET compliance plan that uses calcium and sulfate threshold values and real-time receiving water flows, rather than the default effluent IC25s and receiving water low flows (7Q10). This plan allows the treatment and discharge of effluent volumes needed to avoid reaching critical water levels in the pit.

Stream Biological Monitoring

Mining Client, Montana, USA (2017-present)

Designed and managed benthic macroinvertebrate monitoring program to correspond with long-term surface water monitoring and support decisions on TI waivers, alternative ARARs, and remedy effectiveness at a large NPL site spanning multiple watersheds. He currently leads all field sampling, report development, and stakeholder engagements.

Stream Biological Monitoring

Mining Client, Idaho, USA (2014-present)

Mr. Fulton developed, managed, and provided technical oversight to a stream biomonitoring program (fish and benthic invertebrates) that spans multiple CERCLA sites and watersheds impacted by active and historic phosphate mining. Monitoring activities were tailored to fit within existing state methodologies and protocols from EPA's updated aquatic life criteria for selenium. Monitoring data were used to support use-attainability analyses and develop site-specific selenium standards.

Natural Resource Damage Assessment

Mining Client, Idaho, USA (2015-2023)

Mr. Fulton served as the NRDA project manager on a mining portfolio consisting of seven mine sites and multiple potential responsible parties. He worked with clients, attorneys, economists and other technical experts on settlement strategies and development of terrestrial and aquatic injury assessment plans. On behalf of the responsible parties, he served as the technical expert for fisheries and aquatic life assessments and led all technical and regulatory negotiations with Trustees' technical experts.

Technical Impracticability Evaluation

Mining Client, Montana, USA (2012-2019)

To support a technical Impracticability evaluation of surface water standards at a major NPL site affected by historic smelting operations, Mr. Fulton led fate and transport studies for a variety of metals, modeled hydrology, water chemistry, and performance of remedies to demonstrate that achieving default surface water quality standards are impracticable. Mr. Fulton worked with attorneys, state agencies, and federal agencies on execution of the TI waiver and modifications to the existing Record of Decision.

Bioavailability and Site-Specific Toxicity Studies

Mining Client, Montana, USA (2012-2016)

Designed, proposed, and implemented field and laboratory studies to evaluate the site-specific bioavailability and toxicity of cadmium, copper, and lead to aquatic invertebrates and fish. Studies were used to demonstrate existing remedies and stream conditions are protective of aquatic life uses when site-specific water quality criteria are considered. Site-specific criteria for copper were developed from water effect ratio studies and biotic ligand model calculations performed during seasonal sampling throughout different watersheds.

Watershed Management Plan

Mining Client, Montana, USA (2012-2018)

Technical lead on the development of a long-term surface water management plan for remedy performance and compliance monitoring. He designed surface water, storm water, and biological monitoring plans required for compliance determinations as part of EPA's five-year review process.

Development of Site-Specific Copper Criteria

Mining Client, New Mexico, USA (2009-2016)

Developed and implemented site-specific copper criteria across multiple intermittent and ephemeral drainages at a large smelter-impacted mine site. Mr. Fulton designed work plans, led field work, managed toxicity testing laboratories, and authored reports and petitions to adopt site-specific water quality criteria. In 2015, he provided expert testimony in New Mexico's Triennial Review hearings to support adoption of the site-specific criteria.

Hydrologic Use-Attainability Analysis

Mining Client, New Mexico, USA (2010-2014)

Mr. Fulton conducted multiple UAAs that re-classified ephemeral and intermittent streams to a limited aquatic life use designation. This resulted in a shift from chronic to acute aquatic life criteria for the study streams. He worked with state agencies to reclassify stream reaches based on the UAA study results.

Basin-wide Conceptual Site Model and Information Management

Mining Client, Montana, USA (2010-2014)

Mr. Fulton coordinated the development of a basin-wide conceptual site model that integrated geospatial, physical, chemical, and biological data collected over the past 20+ years to inform regulatory strategy and cost/benefit of remedial alternatives.

Ecological Risk Assessment for Aquatic Life

Tennessee Valley Authority, Tennessee, USA (2011-2012)

Mr. Fulton served as the principal ecological risk assessor for aquatic plants and periphyton affected by a fly-ash spill in a large river and reservoir system. He derived alternative screening levels for aquatic plants based on analysis of literature and site-specific data.

Whole Effluent Toxicity Testing

Mining Client, South Carolina, USA (2011-2012)

Mr. Fulton developed pilot-scale WET tests during the mine permitting process and negotiated alternate test organisms tolerant of high dissolved salts for long-term testing. He provided technical oversight to sampling, stream-flow monitoring, and the toxicity testing laboratory and authored all reports pursuant to the state regulatory program.

Stream Biomonitoring

Midas Gold, South Carolina (2011-2012)

Mr. Fulton designed and performed stream biological and flow monitoring for the Environmental Impact Statement process at a permitted mine. This included work plan development, field coordination and execution, and report development.

Ecological Risk Assessment for Paper Production Site

Industrial Client, California, USA (2009-2011)

Mr. Fulton provided technical support to screening and baseline-level ecological risk assessments for multiple organic and inorganic constitutes in terrestrial and aquatic environments. He led all statistical evaluations, performed risk calculations using food web models and authored report sections.

Development of Tier-2 Water Quality Criteria

Industrial Client, Michigan, USA (2010-2011)

Mr. Fulton developed Tier-2 water quality criteria for several organic constituents in an industrial effluent. He developed toxicity testing protocols for alternative species and derived toxicological benchmarks in accordance with the state regulatory program. Mr. Fulton coordinated the protocol development and testing with the laboratory, performed all Tier-2 criteria calculations, authored all reports, and worked with state agencies to adopt the Tier-2 criteria

Whole Effluent Toxicity Testing

Industrial Client, California, USA (2009-2013)

Mr. Fulton developed a surface-water monitoring and WET testing program in accordance with EPA WET testing methodology at a large industrial site with multiple effluent discharge points. He led all aspects of the study, and negotiated dilution credits for effluent discharge.

Robust Summaries for European REACH program of Mesocosm Stream Studies

Industrial Client, Ohio, USA (2009-2011)

Mr. Fulton assisted in summarizing more than 250 population and community-level endpoints for five surfactant chemicals under the European Union's REACH program. He conducted dose-response modeling on data collected from large, complex mesocosm studies to derive toxicological effect levels required for chemical registration.

Ecological Risk Assessment for Michigan River Floodplain

Industrial Client, Michigan, USA (2009-2011)

Mr. Fulton provided the primary technical support on an ecological risk assessment of PCBs in a river and floodplain system. He developed and executed food-web models, derived alternative toxicity reference values, and co-authored the baseline risk assessment report.

Ecological Risk Assessment for Large Mine Site

Mining Client, New Mexico, USA (2009-2011)

Mr. Fulton developed study plans, performed field work, and statistically analyzed environmental data for an ecological risk assessment at a mining site impacted by historical smelter emissions. He performed risk calculations via food-web modeling and conducted cupric ion activity calculations using site-specific soil chemistry data.

Ecological Risk Assessment for Nevada Mining Site

Mining Client, Nevada, USA (2009-2011)

Mr. Fulton developed and managed an extensive database of bird observations/records on a large NPL site. He prepared weekly and monthly reports to USFWS on bird observations and observed mortalities.

Risk Assessment of Lead Shot under REACH program

Industrial Client, Belgium (2009-2011)

Mr. Fulton assisted in a population-level risk assessment on the effects of lead shot to the gray partridge and buzzard. He conducted binomial probability modeling to estimate ingestion probability and developed population-level effect thresholds based on literature reviews.

Texas Reservoir and Riverine Studies

State of Texas, USA (2004-2007)

Conducted a state-wide limnological assessment of Texas reservoirs and riverine zones. Characterized physical and chemical status of 22 reservoirs across different ecoregions and defined attainable dissolved oxygen levels for riverine sections, where rivers transition into open-water reservoir zones.

Development of Numeric Criteria for Phosphate

State of Texas (2004-2007)
Conducted statewide benthic macroinvertebrate assessments and water quality monitoring to develop numeric criteria for phosphate in streams and river.

Publications

Detering, C, Brix KV, Adzic A, **Fulton BA**, DeForest DK. 2024. Relationships in selenium concentrations among fish tissues to support selenium assessments and regulations. *Environ Toxicol Chem*. *In Press.*

Brooks BW, **Fulton BA**, Hanson ML. 2015. Aquatic toxicology studies with macrophytes and algae should balance experimental pragmatism with environmental realism. *Sci Total Environ*. 536: 406-407.

Fulton BA, Meyer JS. 2014. Development of a regression model to predict copper toxicity to Daphnia magna and site-specific copper criteria across multiple surface-water drainages in an arid landscape. *Environ Toxicol Chem*. 33:1865-1873

Bian J, Berninger JP, **Fulton BA**, Brooks BW. 2013. Nutrient Stoichiometry and concentrations influence silver toxicity in the aquatic macrophyte *Lemna gibba*. *Sci Total Environ*.449: 229-36.

Forbes M, Doyle R, Scott T, Stanley J, Huang H, **Fulton BA**, Brooks BW. 2012. Carbon sink to source: longitudinal gradients of planktonic P:R ratios in subtropical reservoirs. *Biogeochem*. 107:81-93.

Fulton BA, Brain RA, Usenko S, Back JA, Brooks BW. 2010. Exploring *Lemna gibba* thresholds to nutrient and chemical stressors: differential effects of triclosan on internal stoichiometry and nitrate uptake across a N:P gradient. *Environ Toxicol Chem*.29:2363-2370.

Fulton BA, Brain RA, Usenko S, Back JA, King RS, Brooks BW. 2009. Influence of N and P concentrations and ratios on *Lemna gibba* growth responses to triclosan in laboratory and stream mesocosm experiments. *Environ Toxicol Chem*. 28:2610-2621.

Brain RA, Ramirez AJ, **Fulton BA**, Chambliss CK, Brooks BW. 2008. Herbicidal effects of sulfamethoxazole in *Lemna gibba*: using *p*-aminobenzoic acid as a biomarker of effect. *Environ Sci Tecnol*. 42: 8965-8970.

King RS, Back JA, Taylor JM, **Fulton BA**, Brooks BW. 2009. Linking observational and experimental approaches for the development of regional nutrient criteria for wadeable streams. EPA #CP-966137-01. Draft Final Report. U.S. Environmental Protection Agency, Region 6.

Public Meeting and Public Comment Period
Copper water quality criteria for Pajarito Plateau

Public Meeting: September 26, 2023, 2:00 – 3:30 p.m. MDT
Cities of Gold Hotel and Virtual

Public Comment Period: September 25 to November 9, 2023
On behalf of the DOE Environmental Management Los Alamos Field Office, legacy cleanup contractor N3B Los Alamos will conduct a public meeting and 45-day public comment period for adopting new water quality criteria for copper for surface waters around Los Alamos National Laboratory (LANL). The water quality criteria is being developed in accordance with the U.S. Environmental Protection Agency's nationally recommended copper water quality criteria for protection of aquatic life.

A draft report is available for comment at n3b-la.com/outreach. Written and oral comments will be given equal weight and N3B will consider all comments received or postmarked by November 9, 2021. Written comments should be sent to N3B Copper Water Quality Criteria Comments, 1200 Trinity Drive, Suite 150, Los Alamos NM 87544, or email to: N3BOutreach@em-la.doe.gov.

For more information, including virtual meeting details, please visit:
n3b-la.com/outreach |

PETITIONERS' EXHBIT 7

N3B-Los Alamos
1200 Trinity Drive, Suite 150
Los Alamos, New Mexico 87544
(505) 257-7690

Environmental Management
Los Alamos Field Office
1200 Trinity Drive, Suite 400
Los Alamos, New Mexico 87544
(240) 562-1122

Date: January 22, 2024
Refer To: N3B-2024-0021

Communities for Clean Water
c/o Rachel Conn
Amigos Bravos
P.O. Box 238
Taos, NM 87571

Subject: Enclosed is the Updated Copper Site-Specific Water Quality Criteria for the Pajarito Plateau: Demonstration Report, Dated November 20, 2023, and the Response to the Communities for Clean Water Comments on N3B's Draft Copper Criteria for the Pajarito Plateau Report, Dated November 9, 2023

Dear Communities for Clean Water:

On November 9, 2023, the U.S. Department of Energy Environmental Management Los Alamos Field Office (EM-LA) and Newport News Nuclear BWXT-Los Alamos, LLC (N3B) received comments from the Communities for Clean Water (CCW) on the "Copper Site-Specific Water Quality Criteria for the Pajarito Plateau: Demonstration Report" (hereafter, Demonstration Report).

On September 26, 2023, EM-LA and N3B held a public meeting to discuss the Demonstration Report. A public comment period was open from September 25 to November 9, 2023. On November 9, 2023, CCW provided comments and requested a digital copy of Appendix A. EM-LA/N3B appreciate CCW's review and comments on the Demonstration Report, and are pleased to provide the complete Demonstration Report, including Appendix A on CD (Enclosure 1) and the response to CCW's comments (Enclosure 2).

PETITIONERS' EXHIBIT 8

If you have questions, please contact Amanda White at (505) 309-1366 (amanda.white@em-la.doe.gov) or Cheryl Rodriguez at (505) 414-0450 (cheryl.rodriguez@em.doe.gov).

Sincerely,

Troy Thomson
Program Manager
Environmental Remediation
N3B-Los Alamos

Sincerely,

ARTURO DURAN
Digitally signed by ARTURO DURAN
Date: 2024.01.18 09:02:07 -07'00'

Arturo Q. Duran
Compliance and Permitting Manager
Office of Quality and Regulatory Compliance
U.S. Department of Energy
Environmental Management
Los Alamos Field Office

Enclosure(s):

1. Copper Site-Specific Water Quality Criteria for the Pajarito Plateau: Demonstration Report, Dated November 20, 2023 (including a redline strikeout version)
2. Response to Comments on N3B's Draft Copper Criteria for the Pajarito Plateau Report, Provided by Communities For Clean Water, Dated November 9, 2023

cc (letter and enclosure[s] emailed):
Jasmin Lopez-Diaz, EPA Region 6, Dallas, TX
Russell Nelson, EPA Region 6, Dallas, TX
Raymond Martinez, San Ildefonso Pueblo, NM
Dino Chavarria, Santa Clara Pueblo, NM
Kathy Sanchez, Tewa Women United
Kaitlin Bryson, Communities for Clean Water
Joni Arends, Concerned Citizens for Nuclear Safety
Joan Brown, Partnership for Earth Spirituality
Marlene Perrotte, Partnership for Earth Spirituality
Steve Yanicak, NMED-DOE-OB
Christal Weatherly, NMED-OGC
Rick Shean, NMED-RPD
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Susan Lucas-Kamat, NMED-SWQB
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City, State, ZIP+4® Taos, NM 87571

PS Form 3800, April 2015 PSN 7530-02-000-9047 See Reverse for Instructions

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Public Reading Room (EPRR)
PRS website

ENCLOSURE 2

Response to Comments on N3B's Draft Copper Criteria for the Pajarito Plateau Report, Provided by Communities for Clean Water, Dated November 9, 2023

Response to *Comments on N3B's Draft Copper Criteria for the Pajarito Plateau Report*, Provided by Communities For Clean Water Dated November 9, 2023

INTRODUCTION

To facilitate review of this response, the Communities for Clean Water's (CCW's) comments are included verbatim. The U.S. Department of Energy (DOE) Environmental Management Los Alamos Field Office responses follow each CCW comment.

SPECIFIC COMMENTS

CCW Comment

1. <u>Aggregation of Data:</u> The proposed site-specific water quality criteria for copper creates a multi-linear regression based on an aggregate of data across the Pajarito Plateau watershed – a 43 square mile area that encompasses nine major watersheds.

EM-LA/N3B should conduct an analysis to demonstrate that there is no substantial difference in site specific criteria between the major watersheds (i.e., Sandia vs Mortandad) and developed and undeveloped watersheds.

DOE Response

1. Just as the hardness-based and biotic ligand model (BLM) copper criteria vary according to water chemistry, so will the multiple linear regression- (MLR-) based copper site-specific water quality criteria (SSWQC). If there are significant differences in water chemistry between watersheds (or in developed versus undeveloped portions of the same watershed), then it's reasonable to expect respective differences in SSWQC values. Protectiveness of the SSWQC, however, would be the same regardless of water quality condition. The SSWQC (or the hardness-based criteria or BLM) varies with water quality because bioavailability and toxicity also vary in response to water chemistry. For example, Los Alamos National Laboratory's (LANL's) Individual Permit currently includes watershed-specific target action levels for copper, which vary according to watershed-specific average hardness. Therefore, the evaluation CCW proposes would neither support nor invalidate the appropriateness of the SSWQC.

   The demonstration report already includes a detailed discussion (particularly in Section 5.4 and Appendix B) of the statistical evaluations conducted to date that show how stream hydrology and other watershed factors were considered when developing the MLR-based SSWQC. Ultimately, we selected a three-parameter MLR (with a squared pH term) without watershed-specific features. We found that the model was not meaningfully improved by adding more parameters (hydrology, land use, fire, etc.). For example, Table 5-4 presents the statistical outcome of various models that considered hydrology; including hydrology as a feature improved predictive accuracy by 0.2%.

CCW Comment

2. ***<u>Clarity between BLM and MLR:</u>* *Some sections of the report, particularly towards the beginning of the document, still misrepresent the use of the Biotic Ligand Model (BLM) vs Multiple Linear Regression (MLR) (e.g., page 20).***

   The report is still referring to the method used as "BLM" when really it is an MLR approach. Please update references throughout and submit a new version to the NMED Surface Water Quality Bureau, the N3B website, and provide and electronic notice to the public.

DOE Response

2. To be responsive to this comment, we have reviewed the document and attempted to shift the emphasis originally placed on the BLM to the MLR. For example, the first sentence in Section 4 calls the SSWQC "MLR-based," and Section 4.3 describes the use of MLR. However, keeping ample discussion and reference to the BLM remains integral to the discussion of the MLR because the BLM is the underlying basis for the MLR:

   - Many of the samples in the dataset were collected and analyzed for the purpose calculating BLM criteria.
   - The full dataset, which includes some estimated parameter values, was aggregated with the specific purpose of using the BLM.
   - The MLR dataset (Appendix A) includes BLM outputs (not just inputs).
   - BLM outputs were used as the dependent variable in the MLR equation.

   The purpose of the MLR is to estimate BLM outputs (i.e., EPA's recommended criteria) using 3 water quality inputs (pH, DOC, and hardness) rather than the 12 default inputs required by the BLM. Because of the high degree of accuracy of the MLR for predicting BLM output, the copper SSWQC are consistent with the BLM. Throughout the report, we emphasize that the MLR provides an accurate estimate of the BLM, which we rigorously demonstrate in the report; we never conflate the two models.

   CCW mentions page 20 as an example where the BLM is mentioned. In this instance, we only find mention of "BLM data," by which we mean the dataset of water-quality inputs to the BLM. Because these data were input into the BLM to generate outputs used in the MLR development, this terminology is accurate and appropriate as currently used.

CCW Comment

3. ***<u>Rationale For Removing Samples from the Modeling:</u>* *Please clarify the number of stormwater samples removed from the modeling dataset as briefly described on page B-5 and B-6.***

   The text implies that 94 stormwater samples were removed. CCW requests that the rationale for what samples were used and what samples were removed be more clearly defined and explained in the new version of the report.

DOE Response

3. Section B2.2 provides a discussion of the stepwise compilation of data, including methods for estimating water chemistry data, as appropriate and based on regulatory guidance, to establish a highly robust dataset. This involved excluding samples where DOC was neither measured nor could be estimated, those that lacked pH data, and/or those where other ions could not be estimated or that do not have reasonable default values (e.g., from EPA [2007] copper BLM guidance). This step in the aggregation process resulted in a dataset with 611 samples.

   Section B2.3 discusses the reduction of this dataset from 611 to 517 samples (the difference being the 94 samples that CCW references in their comment) and provides the reasons that the dataset was further reduced:

   1) 4 duplicate (redundant) entries were observed in the dataset and reduced to single entries.

   2) 76 stormwater discharge samples, representing “end-of-pipe” or runoff samples of stormwater, were identified and removed, so that the BLM dataset only includes ambient water samples.

   3) 14 samples were removed that had pH, DOC, or hardness measurements outside of the BLM’s prescribed (calibrated) range.

   In total, this amounts to 94 samples excluded, per available EPA guidance.

   The remaining 517-sample dataset includes only:

   1) samples with the complete set of BLM parameters;

   2) unique sampling events and measurements;

   3) ambient (i.e., instream) samples; and

   4) samples with BLM parameters within prescribed calibration ranges, meaning that no extrapolation was required to develop the MLR.

CCW Comment

4. ***<u>Please provide Appendix A:</u> CCW requests a copy via flash drive of Appendix A (BLM Dataset for Pajarito Plateau Surface Waters).***

   The requested data can be mailed to CCW c/o Amigos Bravos, P.O. Box 238, Taos, NM 87571.

DOE Response

4. Appendix A will be uploaded to the Electronic Public Reading Room as an Excel file with the final Demonstration Report.

REFERENCE

EPA. 2007. Aquatic life ambient freshwater quality criteria - copper, 2007 revision. EPA-822-R-07-001. Office of Water, US Environmental Protection Agency Washington, DC.

DRAFT WORK PLAN: DEVELOPMENT OF SITE-SPECIFIC COPPER CRITERIA FOR SURFACE WATERS OF THE PAJARITO PLATEAU NEW MEXICO

Prepared for:
N3B Los Alamos

July 6, 2020

Prepared by: Windward environmental LLC

200 West Mercer Street, Suite 401 ⬩ Seattle, Washington ⬩ 98119

PETITIONERS' EXHIBIT 9

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Acronyms

%HA	percent humic acid
AU	assessment unit
BLM	biotic ligand model
Cu	copper
CWA	Clean Water Act
DOC	dissolved organic carbon
DOE	Department of Energy
DOE-OB	Department of Energy Oversight Bureau (of NMED)
DQA	data quality assessment
DQO	data quality objective
EIM	Environmental Information Management
EPA	US Environmental Protection Agency
HUC	hydrologic unit code
IP	individual permit
The Laboratory	Los Alamos National Laboratory
LAC	Los Alamos County
MLR	multiple linear regression
MSGP	multi-sector general permit
N3B	Newport News Nuclear BWXT Los Alamos
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
NPDES	National Pollutant Discharge Elimination System
NMWQS	New Mexico water quality standards
SEP	supplemental environmental project
SSWQC	site-specific water quality criteria
SWMU	solid waste management unit
SWQB	Surface Water Quality Bureau (of NMED)

TAL	target action level
TR	Triennial Review
USGS	US Geological Survey
WER	water effect ratio
Windward	Windward Environmental LLC
WP	work plan
WQBEL	water quality-based effluent limit
WQC	water quality criteria
WQCC	Water Quality Control Commission
WQS	water quality standard
WWTF	wastewater treatment facility

1 Introduction

The purpose of this document is to present a Work Plan (WP) for the development of copper (Cu) site-specific water quality criteria (SSWQC) for surface waters of the Pajarito Plateau in Los Alamos County, New Mexico. It identifies the methods, available data, and spatial boundaries to be used.

Current ambient water quality criteria (WQC) for Cu in New Mexico are consistent with the U.S. Environmental Protection Agency (EPA) 1996 WQC, which are based on a standard equation that only considers the effects of water hardness on Cu bioavailability. In 2007, EPA released updated nationally recommended WQC for Cu that take additional water quality parameters into account, reflecting significant advancements in the scientific understanding of metal speciation, bioavailability, and toxicity. These advancements were incorporated into the biotic ligand model (BLM), which is a metal bioavailability model that can be used to develop Cu WQC (EPA 2007). The New Mexico Water Quality Standards (NMWQS) recognize the EPA 2007 BLM for Cu as an applicable method for developing Cu SSWQC for New Mexico surface waters (20.6.4.10 NMAC).

This WP presents a proposed path forward for deriving BLM-based Cu SSWQC for surface waters of the Pajarito Plateau in the vicinity of Los Alamos National Laboratory (the Laboratory). The physical and chemical characteristics of Pajarito Plateau surface waters are rigorously monitored at a variety of locations under several programs, so it is a suitable setting for BLM-based Cu SSWQC.

New Mexico's most recent (2018-2020) Clean Water Act (CWA) §303(d)/305(b) Integrated Report (IR; New Mexico Environment Department [NMED] 2018) identifies surface water segments of the Pajarito Plateau as not supporting designated aquatic life uses due to Cu concentrations along with other causes. The IR impairment category provided for Cu in these surface waters is "5/5B", defined as "impaired for one or more designated or existing uses and a review of the water quality standard will be conducted" (NMED 2018)[1]. Importantly, these assessments are based on the EPA 1996 hardness-based WQC (EPA 1996) and may be inconsistent with the best available science and EPA WQC.

In 2018, application of EPA's 2007 BLM-based WQC to a broad range of Pajarito Plateau surface waters showed the current hardness-based Cu WQC are often

[1]New Mexico's 2016-2018 IR listed surface water segments of the Pajarito Plateau under the "5/5C" impairment category, defined as "impaired for one or more designated or existing uses and additional data will be collected before a TMDL is scheduled". The change from "5/5C" to "5/5B" for Pajarito Plateau surface waters was described in the Assessment Rationale for the 2018-2020 Integrated List: "specific impairments are noted as IR Cat 5B to acknowledge LANL's on-going discussions and research regarding applicable water quality standards on the Pajarito Plateau for these parameters."

unnecessarily stringent, yielding 36% acute WQC exceedances that would not have occurred under potential BLM-based Cu WQC (Windward 2018). Consequently, continued application of the current hardness-based Cu WQC could lead to unnecessary regulatory actions. Thus, the overall goal of this WP is to initiate a process that employs the best available science and corresponding EPA and NMED guidance to derive SSWQC for Cu that can be applied to the surface waters of the Pajarito Plateau.

1.1 OBJECTIVES

Newport News Nuclear BWXT Los Alamos (N3B) proposes to develop this proposal, in cooperation with NMED, as a water quality standard rulemaking to be taken forward with the NM Water Quality Control Commission (WQCC). Specific objectives of this WP are as follows:

- Present a plan for developing Cu SSWQC for surface waters of the Pajarito Plateau that will provide a basis for a subsequent technical report and petition to the NM WQCC for adopting Cu SSWQC
- Establish a process for review and comments on the proposed Cu SSWQC by NMED and EPA, other stakeholders, and the general public consistent with 20.6.4.10.D(3) NMAC
- Establish the initial technical approach for developing Cu SSWQC consistent with acceptable methods in 20.6.4.10.D(4) NMAC

1.2 PROCESS AND SCHEDULE

This section identifies the general process and anticipated schedule for developing a petition and engaging stakeholders to review the proposed Cu SSWQC prior to the WQCC rulemaking process. The N3B team will work with NMED to confirm this process and schedule, and refine elements where needed, including identifying milestones for N3B's interactions with NMED, EPA, and the public leading up to the WQCC hearing.

The "Triennial Review" (TR), Section 303(c) of the CWA requires States and Tribes to review and update their WQS at least every three years. In early 2020, the NMED notified stakeholders of their intent to initiate the next TR. The relevant milestones leading up to an eventual WQCC water quality standard rulemaking hearing remain to be determined. It is not yet clear if the petition for Cu SSWQC for surface waters of the Pajarito Plateau should be proposed to the WQCC during the next TR or during a separate WQCC rulemaking. The N3B team will work with NMED to make this determination.

Figure 1 presents a preliminary TR schedule and the phases that could include N3B's participation if it were to propose a Cu SSWQC petition during the TR. This schedule was developed in early 2020 assuming the TR will occur in the second quarter of 2021. Updates to this schedule, contingent on the TR or a separate WQCC hearing, will be made as needed and as more detailed interim milestones are available.

1.2.1 Cu SSWQC Work Plan

The first milestone will be for the N3B team to refine this initial WP based on input from the NMED and EPA. Although this WP is not a specific requirement pursuant to adopting SSWQC under 20.6.4.10 NMAC, it has been developed to: (1) define a process to facilitate review and comment from NMED and EPA on the proposed SSWQC prior to preparing the petition for a potential WQCC rulemaking, (2) identify the approach for conducting stakeholder and public review, comment, and responses on the proposed Cu SSWQC, and (3) establish a general process and schedule for developing a Cu SSWQC petition.

N3B will provide the initial draft WP to EPA and NMED for review prior to a teleconference to discuss initial comments. Formal comments will be requested using a process like that used during the 2018 BLM Data Quality Objectives/Data Quality Assessment (DQO/DQA) document development (e.g., using the N3B comment resolution form). This WP will be updated to address comments and a revised version will be provided as appropriate.

1.2.2 Cu SSWQC Technical Report

A technical report documenting the details of Cu SSWQC development will be submitted to NMED and EPA for review and comment. One or more teleconferences will be held to review the key findings and recommendations of the report. The overall purpose of the technical report will be to present and justify the derivation of Cu SSWQC (pursuant to 20.6.4.10 NMAC). As such, the technical report will provide the technical basis for a Cu SSWQC petition and is anticipated to become a technical exhibit supporting the proposal provided to WQCC.

Specific objectives of the technical report will be to:

- Present the site-specific surface water dataset from which BLM-based Cu SSWQC will be derived. Windward (2018) previously applied EPA's DQO/DQA process to generate and evaluate potential BLM WQC based on surface water data collected from the Pajarito Plateau between 2005 and 2017. This approach will be applied to data collected in 2018 and 2019 to establish an updated, site-specific dataset suitable for deriving BLM-based Cu SSWQC.
- Generate BLM-based Cu WQC using data from surface water sampling events conducted through 2019 that meet the DQO/DQA process
- Develop a site-specific multiple linear regression (MLR) equation that accurately predicts BLM-based Cu WQC

- Statistically evaluate the performance of the MLR equation on temporal and spatial scales relevant for generating Cu SSWQC for surface waters of the Pajarito Plateau
- Considering: (1) a BLM software approach and (2) an MLR-based equation as a simplified approach, recommend a final Cu SSWQC approach
- Identify the specific waters of the Pajarito Plateau to which the proposed Cu SSWQC would apply

1.2.3 Stakeholder Involvement

A requirement for a SSWQC petition pursuant to 20.6.4.10 NMAC is to "describe the methods used to notify and solicit input from potential stakeholders and from the general public in the affected area, and present and respond to the public input received."

N3B anticipates completing the following actions to satisfy this requirement:

- Provide this WP and the Technical Report to NMED and EPA and refine these documents in collaboration with these agencies
- Provide public notices in local newspaper and other platforms to notify the general public of a proposal for SSWQC and provide access to the Cu SSWQC Technical Report for public/stakeholder review and comment
- Provide a means to receive written public comments such as via email or a web-based platform
- Hold local public meetings or teleconferences to present the proposed Cu SSWQC and respond to any verbal input received
- Document all public input received and responses provided in a Cu SSWQC petition (see below section)

1.2.4 Cu SSWQC Petition

In accordance with WQCC regulations (20.1.6.200.A and 20.6.4.10.D(3) NMAC), any person may petition the WQCC to adopt SSWQC. The WQCC regulations require that a petition for the adoption of SSWQC requires "be in writing and shall include a statement of the reasons for the regulatory change. The petition shall cite the relevant statutes that authorize the commission to adopt the proposed rules and shall estimate the time that will be needed to conduct the hearing. A copy of the entire rule, including the proposed regulatory change, indicating any language proposed to be added or deleted, shall be attached to the petition. The entire rule and its proposed changes shall be submitted to the commission in redline fashion, and shall include line numbers." 20.1.6.200.B NMAC. In addition, the regulations require that a petition include the following:

(a) Identify the specific waters to which the SSWQC would apply

(b) Explain the rationale for proposing the SSWQC

(c) Describe the methods used to notify and solicit input from potential stakeholders and from the general public in the affected area, and present and respond to the public input received

(d) Present and justify the derivation of the proposed SSWQC

20.6.4.10.D(3) NMAC. A petition for Cu SSWQC will be developed based on: (1) conclusions and recommendations presented in the final Technical Report, (2) NMED and EPA comments, and (3) input from other potential stakeholders and the general public. The petition will include all information required under 20.1.6.200 and 20.6.4.10 NMAC for WQCC review.

2 Site Setting

The following sections provide general background information regarding geography, geology, hydrology, and permitted discharges.

2.1 Geographic Setting

The Laboratory occupies approximately 36 mi^2 of Department of Energy (DOE) lands in Los Alamos County in north-central New Mexico, approximately 60-mi north-northeast of Albuquerque and 25 mi northwest of Santa Fe (Figure 2). The general area encompassing the Laboratory, towns of Los Alamos and White Rock, Bandelier National Monument, San Ildefonso Pueblo lands, West slopes of the Jemez Mountains and other surrounding areas, is known geographically as the Pajarito Plateau. Lands north, west, and south of the Laboratory are largely undeveloped areas held by the Santa Fe National Forest, the U.S. Bureau of Land Management, Bandelier National Monument, and Los Alamos County (LANL 2013). The communities closest to the Laboratory are the towns of Los Alamos, located just to the north of the main Laboratory complex, and White Rock, located a few miles to the east-southeast.

2.2 Geologic Setting

The Laboratory is situated on fingerlike mesas capped mostly by the Bandelier Tuff. The Bandelier Tuff consists of ash fall, pumice, and rhyolite tuff with thicknesses of 1,000 feet on the western side of the plateau, thinning to about 260 feet eastward above the Rio Grande (Broxton et al. 1995). The mesa tops slope from elevations of approximately 7,800 ft on the flanks of the Jemez Mountains to about 6,200 ft at their eastern terminus above the Rio Grande Canyon.

2.3 Hydrologic Setting

The Laboratory lies within a segment of the upper Rio Grande watershed denoted by the U.S. Geological Survey 8-digit hydrologic unit code (HUC) 13020101. The upper Rio Grande is a large watershed (approximately 7,500 mi^2) that generally flows from north to south. The New Mexico portion of the watershed is within seven counties: Rio Arriba, Taos, Santa Fe, Los Alamos, Sandoval, Mora, and San Miguel.

Surface water runs off the Pajarito Plateau through steep and narrow canyons, flowing primarily southeast to the Rio Grande; however, surface water flows rarely reach the Rio Grande River due to the limited flow durations and infiltration in canyon reaches upgradient of the Rio Grande. Most drainages on the Pajarito Plateau are ephemeral or intermittent and flow only for limited periods in response to rainfall or snowmelt. Summer monsoonal thunderstorms are the sole contributors to flow in the many ephemeral waters, which otherwise remain dry for most of the year. A few canyons contain relatively short segments of intermittent and/or perennial flow attributable to springs, snowmelt, and industrial/municipal effluent discharges.

The Laboratory encompasses seven major watersheds: Los Alamos, Sandia, Mortandad, Pajarito, Water/Canon de Valle, Ancho, and Chaquehui Canyons. Many tributaries to these canyons within the Laboratory are identified as smaller sub-watersheds with other names. Additional watersheds outside of the Laboratory include the § 98 waters to the North (Pueblo, Bayo, Guaje, and Rendija Canyons and their tributaries). A map depicting the Pajarito Plateau, related water bodies, the Laboratory, towns of Los Alamos and White Rock, and Pueblo and County boundaries is presented in Figure 3.

2.4 New Mexico Classifications of the Pajarito Plateau Surface Waters

For the focus of this WP, the Pajarito Plateau waters in the vicinity of the Laboratory include the following three "segments" classified by the State of New Mexico in NMAC:

1. Perennial waters in Bandelier National Monument (20.6.4.121 NMAC), a stream known as Rito de Frijoles
2. Four perennial portions of waters within the Laboratory located in Pajarito Canyon, Sandia Canyon, Water Canyon, and Canon de Valle (20.6.4.126 NMAC)

3. Ephemeral and intermittent portions of watercourses within the Laboratory encompassing segments of 12 major and minor named canyons[2] (20.6.4.128 NMAC)

A number of additional watercourses of the Pajarito Plateau have not been identified as specific segments in NMAC so they are subject to the statewide intermittent waters segment classification (20.6.4.98 NMAC). These watercourses are not within the boundary of the Laboratory, and include Pueblo, Bayo, Rendija, Guaje and other canyons, as well as unclassified tributaries and reaches of §128 waters upstream and/or downstream of the Laboratory. In addition to many solid waste management units (SWMUs) within the Laboratory, the NPDES IP regulates certain SWMUs located outside of the Laboratory and in outlying DOE property that drain to §98 watercourses. Each classified segment specifies designated uses and applicable WQC which collectively are the applicable WQS.

The NMED has assigned Assessment Units (AUs) to one or more reaches of each classified segment. The segments associated with Pajarito Plateau encompass 49 AUs, of which 38 are located within the Laboratory or receive discharges regulated by the IP and the LAC WWTF permit. NMED's § 303(d)/305(b) assessments have resulted in § 303(d) listings for several Pajarito Plateau AUs, notably 12 AUs within or adjacent to the Laboratory, determined to be impaired by Cu (NMED 2012b, 2018). Some of these or additional AUs are also listed as impaired by aluminum and other parameters.

Most water bodies within the Laboratory vicinity are classified as ephemeral or intermittent waters (§ 128), which are designated with a limited aquatic life use, so according to NMAC these water bodies are subject only to acute WQC for aquatic life. Just a few water bodies in the area are classified as perennial waters, which designate higher-level aquatic life uses that apply both acute and chronic aquatic life WQC , i.e., Upper Sandia Canyon, and isolated segments of Canon de Valle and Pajarito Canyon linked with springs(§ 126); and Rio de Frijoles in Bandelier National Monument (§ 121). The unclassified waters (§ 98) are designated with a marginal warm water aquatic life use, which in turn also applies both acute and chronic WQC.

2.6 NPDES Permitted Discharges

The National Pollutant Discharge Elimination System (NPDES) regulates four principal types of discharges to Pajarito Plateau waters:

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[2] Ephemeral and intermittent surface waters within the vicinity of the Laboratory that are currently designated in 20.6.4.128 NMAC include : Mortandad Canyon, Canada del Buey, Ancho Canyon, Chaquehui Canyon, Indio Canyon, Fence Canyon, Portrillo Canyon and portions of Canon de Valle, Los Alamos Canyon, Sandia Canyon, Pajarito Canyon, and Water Canyon.

- Storm water discharges associated with legacy contamination and industrial activities are regulated under the Individual NPDES Storm Water Permit (Individual Permit [IP]; Permit No. NM0030759)
- Storm water discharges associated with current industrial activities are regulated under EPA's NPDES Multi-Sector General Permit (MSGP) Nos. NMR050011, NMR050012, and NMR050013.
- Industrial and sanitary wastewater, and cooling water discharged from 11 outfalls are regulated under NPDES Permit No. NM0028355
- Municipal sanitary wastewater discharged to Lower Pueblo Canyon by the Los Alamos County (LAC) wastewater treatment facility (WWTF) is regulated under NPDES Permit No. NM0020141

As discussed already, the IP target action levels (TALs), MSGP benchmarks, and water quality-based effluent limits (WQBELs) for Cu applicable to Laboratory and LAC NPDES wastewater permits are currently based on New Mexico's hardness-based dissolved Cu WQC (20.6.4.900 NMAC). However, in the 2019 draft IP Fact Sheet, EPA suggested that BLM-based values may be considered for effluent benchmarks if BLM-based Cu SSWQC are adopted into NMWQS and NMED and N3B reach agreeable BLM values through the annual sampling implementation plan.

2.6 SPATIAL BOUNDARIES FOR SSWQC

In the general context of SSWQC, a "site" is not necessarily limited to a particular discharge or reach of a waterbody and can span from a segment to an entire watershed or larger area (EPA 1994). For the purpose of developing Cu SSWQC applicable to the Pajarito Plateau, the "site" will be limited to those water bodies with water quality data that meet DQOs similar to those described in Windward (2018). This area is expected to encompass most or all of § 98, 121, 126 and 128 surface waters of the Pajarito Plateau in the vicinity of the Laboratory including those in LAC and the towns of Los Alamos and White Rock (see Figure 3). This area includes the seven major watersheds and associated sub-watersheds described above.

3 Regulatory Background on SSWQC

This section provides background on developing SSWQC in accordance with EPA guidance and NMWQS.

3.1 CONDITIONS AND METHODS FOR DEVELOPING SSWQC

EPA's regulation at 40 CFR 131.11(b)(1)(ii) provides that states and tribes may adopt water quality criteria that are "modified to reflect site-specific conditions." As with all criteria, SSWQC must be based on sound scientific rationale, protect designated uses, and are subject to EPA review and approval or disapproval under § 303(c) of the Clean Water Act (CWA; EPA 2017).

The NMWQS specify the following site-specific conditions relevant for developing SSWQC (20.6.4.10.D(1) NMAC):

(a) Actual species at a site are more or less sensitive than those used in the national criteria data set;

(b) Physical or chemical characteristics at a site such as pH or hardness alter the biological availability and/or toxicity of a chemical;

(c) Physical, biological or chemical factors alter the bioaccumulation potential of a chemical;

(d) The concentration resulting from natural background exceeds numeric criteria for aquatic life, wildlife habitat or other uses if consistent with Subsection E of 20.6.4.10 NMAC; or

(e) Other factors or combination of factors that upon review of the [Water Quality Control Commission] may warrant modification of the default criteria, subject to EPA review and approval.

The NMWQS, 20.6.4.10.D(4) NMAC, state that derivation of SSWQC shall rely on scientifically defensible methods, which include (but are not limited to):

(a) The recalculation procedure, the water-effect ratio (WER) for metals procedure or the resident species procedure as described in the water quality standards handbook (EPA-823-B-94-005a, 2nd edition, August 1994);

(b) The streamlined WER procedure for discharges of copper (EPA-822-R-01-005, March 2001);

(c) The biotic ligand model as described in aquatic life ambient freshwater quality criteria – copper (EPA-822R-07-001, February 2007);

(d) The methodology for deriving ambient water quality criteria for the protection of human health (EPA-822-B-00-004, October 2000) and associated technical support documents; or

(e) A determination of the natural background of the water body as described in Subsection E of 20.6.4.10 NMAC.

The composition of aquatic species and site-specific metal bioavailability are relevant to developing Cu SSWQC for the Pajarito Plateau. The recalculation procedure addresses only site-specific species composition. The WER procedure and BLM-based Cu WQC address the influence of site-specific water quality on metal bioavailability. Employing the WER procedure is a well-known means of adjusting WQC based on the bioavailability of metals due to water chemistry parameters other than hardness. However, because a WER is empirically derived, it only accounts for the interactions of water quality parameters and their effects on metal toxicity measured in water samples collected at a specific location and time (EPA 1994, 2001, 2007). In addition, multiple WERs may be needed for multiple watersheds (EPA 1994). The streamlined Cu WER procedure (EPA 2001) reduces the scope of EPA's 1994 WER approach by relying on a single test species and limiting numbers of samples but is not well suited for multiple discharge scenarios such as those of the Pajarito Plateau.

Because of these limitations, EPA (2007) recommends the Cu BLM for developing Cu SSWQC because it explicitly and quantitatively accounts for the effect of individual water quality parameters that modify Cu toxicity and can be applied more cost-effectively and easily than a WER, and hence more frequently across spatial and temporal scales. A spatially and temporally robust dataset for deriving BLM-based SSWQC consistent with EPA 2007 has already been collected by N3B and evaluated as described in Section 4. For these reasons, the EPA 2007 BLM-based Cu WQC is the method by which Cu SSWQC will be derived for surface waters of the Pajarito Plateau.

In addition, biological monitoring has been conducted on many occasions in various surface waters of the Pajarito Plateau (LANL 2017); such data provide an indication of resident aquatic life. Therefore, these data will also be evaluated relative to the species in the toxicity dataset used by EPA to derive their nationally recommended BLM-based Cu WQC. The EPA 2007 WQC for Cu and the Cu BLM are described in the following sections.

4 BLM-Based Cu SSWQC

This section provides background information on the EPA's BLM-based Cu WQC and considerations for deriving BLM-based Cu SSWQC for the Pajarito Plateau.

4.1 BLM Background

Since EPA's first publication of hardness-based Cu WQC in 1984, new data from a variety of sources have become available on Cu toxicity and its effects on aquatic life. In 2007, EPA released nationally recommended WQC for Cu based on the BLM. The BLM is a software program that models the speciation and complexation of Cu based on 10 water chemistry parameters (temperature, pH, dissolved organic carbon [DOC], calcium, magnesium, sodium, potassium, sulfate, chloride, and alkalinity[3]).

While BLMs have been developed for multiple metals[4] besides Cu, to date EPA has only published national BLM-based WQC for Cu. EPA published the current Cu WQC in 2007, along with related BLM guidance documents (EPA 2012, 2016). The States of Oregon and Idaho have adopted the EPA 2007 BLM-based Cu WQC statewide as a replacement for the former hardness-based criteria (EPA 1996), while other states have adopted it incrementally or under SSWQC provisions only. As of June 2018, 31 states allow the BLM (either statewide or on a site-specific basis) and 11 states are considering adopting the BLM into their state WQS (Copper Development Association [CDA] and GEI Consultants Inc. [GEI], 2018).

The BLM itself is a proprietary software, which is publicly available at no cost. The BLM Windows® Interface Application allows the user to run the BLM to generate "Cu WQC" and in two other modes[5]. When run in Cu WQC mode, the BLM software generates the EPA 2007 acute and chronic instantaneous Cu WQC based on the input dataset for the location and sample of interest.

4.2 AVAILABLE BLM IMPLEMENTATION GUIDANCE

There are two primary considerations for implementing the Cu BLM: (1) quality and availability of all input data required to generate BLM-based WQC, and (2) generation of one or more BLM-based WQC values for a given waterbody and a particular regulatory use. Both needs are briefly discussed below.

Several BLM implementation guidance documents are available that address data availability, completeness and quality requirements for applying the BLM to generate Cu WQC (ODEQ 2016a, b; IDEQ 2017, IDNR 2016; EPA 2003, 2012, 2016a; Windward 2019). The BLM-based Cu WQC tend to be most sensitive to pH and DOC inputs (and in some cases cations associated with hardness). However, because the BLM is less sensitive to other cations, anions, alkalinity, and temperature, these inputs can often be estimated with minimal effect on the BLM outcomes.

In addition to addressing data inputs, the available implementation guidance discusses various options for applying the BLM to a given waterbody. Because some

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[3] Humic acid, as a percent of dissolved organic matter (%HA), is an input parameter to the BLM but is not generally measured so a default value of 10% is recommended by EPA in the absence of site-specific HA data.

[4] Other BLM versions have been developed for aluminum, cadmium, lead, nickel, silver, zinc and development of BLMs for other metals is ongoing (e.g., cobalt; Brix et al. 2017).

[5] When run in speciation mode, the BLM will predict the organic and inorganic chemical speciation in the water column and the corresponding amount of metal accumulated on the biotic ligand (i.e., a gill or a homologous respiratory organ). When run in toxicity mode for Cu, the BLM will predict the amount of metal required to cause acute or chronic toxicity to a specified organism.

BLM input parameters may vary both temporally and spatially, BLM-derived WQC for a given waterbody may also vary accordingly. The extent of spatial variability depends on the scale by which a "site" is defined (Section 2.6). In contrast, temporal variability in BLM-derived WQC may occur due to seasonal changes in water quality parameters and other natural sources of variability. However, these sources of variability are not unique to the BLM or Cu, as other WQC for other metals and ammonia can vary spatially and temporally as functions of certain water quality parameters (e.g., hardness, pH, temperature).

Considering these sources of variability and the diversity of water bodies to which the BLM can be applied, EPA suggests that in general enough data should be available to characterize and manage the spatial and temporal variability of the site. Importantly, as described in Section 4.3, a comprehensive, site-specific dataset is available to characterize such variability for the purpose of deriving BLM-based SSWQC. This analysis will be presented in a subsequent Technical Report. While final implementation procedures are beyond the scope of a Cu SSWQC petition, pursuant to comments from NMED and EPA, N3B anticipates providing general recommendations for implementation in the Technical Report.

4.3 AVAILABLE SITE-SPECIFIC DATA AND DQO/DQA PROCESS

N3B has collected a relatively large BLM dataset in anticipation of an eventual proposal to adopt the EPA 2007 Cu WQC in New Mexico. This dataset comprises many surface water monitoring locations on the Pajarito Plateau in the vicinity of the Laboratory. Windward (2018) developed DQOs to select appropriate datasets and determine their usability for generating BLM-based Cu SSWQC (and BLM-based values for aluminum, lead, and zinc). Staff from the NMED[6] participated in the review of the DQOs and the 2018 report. A brief summary of the DQO/DQA results from Windward (2018) follows.

Windward (2018) identified 457 sampling events across 48 locations for which complete or sufficiently complete BLM chemistry inputs were available and usable[7]. The dataset spans the period from 2005 to 2017 across the watersheds of the Pajarito Plateau described in Section 2.5. The 48 surface water sampling locations represent two distinct groups: (1) 12 surface waters with watersheds outside of, or upstream

[6] NMED staff from SWQB and DOE Oversight Bureau (DOE-OB) participated in kickoff meetings in March 2018, and submitted comments on the draft DQO/DQA report that were addressed in the April 2018 BLM DQO/DQA report. NMED staff also participated with EPA Region 6 staff in an October 2018 webinar to review and discuss the BLM findings and their potential use as storm water monitoring TALs in context of the new IP.

[7] Data aggregation methods for establishing sufficient datasets to generate BLM-based IWQC are described in detail in Windward (2018).

from, the Laboratory facility and Los Alamos townsite (undeveloped landscapes[8] labeled "natural background" in Figure 3), and (2) 36 surface waters within or downstream of the Laboratory facility and Los Alamos Townsite and other unincorporated areas of LAC (labeled "LANL surface waters" in Figure 3). Many locations are gaging stations operated by N3B, which have relatively long periods of water quality and streamflow monitoring data. The 457 sampling events also represent a broad range of hydrologic conditions including snowmelt, baseflow, and stormflow.

After Windward (2018) completed the DQO/DQA process, N3B collected additional surface water BLM datasets in 2018 and 2019. Therefore, the previously established dataset will be augmented with 2018 and 2019 surface water monitoring data consistent with the DQO/DQA process presented in Windward (2018). The updated dataset will be presented in the subsequent Technical Report along with a technical analysis and proposal of BLM-based SSWQC for surface waters of the Pajarito Plateau.

4.4 OPTIONS FOR APPLYING THE BLM TO DERIVE SSWQC

Despite EPA having recommended BLM-based Cu WQC more than 12 years ago, only two states have fully adopted the BLM-based Cu WQC as statewide criteria in their state WQS. Many other states, including New Mexico, allow the use of the BLM to set SSWQC, but this process typically requires years of data collection, evaluation, petitions for rulemaking and agency approvals. These delays and limitations appear to be due to the perception that the BLM: (1) is too complicated and requires skill/training to utilize, (2) is not sufficiently transparent , and/or (3) requires too many input variables, some of which are typically not collected by State agencies. Furthermore, although BLM implementation guidance documents are available, their approaches may be somewhat inconsistent or incomplete for purposes of replacing statewide WQC or developing SSWQC.

To address many of these issues, N3B proposes to develop a site-specific MLR equation that accurately predicts BLM-based WQC. Such an approach was adopted in Georgia in 2016, whereby a two-parameter, BLM-based MLR equation was approved by EPA as the SSWQC for Buffalo Creek (Resolve Engineering Inc. 2015, EPA 2016b). As a software replacement, the MLR approach, if shown to be robust and reasonably accurate, could reduce effort and sampling costs significantly while incorporating the scientific rigor afforded by the BLM. Preliminary evaluations of the site-specific BLM dataset show the MLR approach is technically feasible and promising in terms of its

[8] Data from the various "natural background" locations have been evaluated in various N3B reports that have characterized background water quality conditions (LANL 2013, 2018, 20120). Data from four of these natural background locations were collected as part of the Supplemental Environmental Project (SEP) in collaboration with NMED, including four of the five natural background locations in the Rio de Frijoles watershed which flows through the Bandelier National Monument.

performance in estimating BLM-based WQC across surface waters of the Pajarito Plateau.

N3B's goal is to develop a site-specific MLR equation that accurately predicts acute and chronic BLM-based Cu WQC and that is a more transparent and readily usable option for SSWQC than the BLM software/model approach. Multi-regression analyses will be conducted between BLM-based WQC and corresponding water chemistry (BLM inputs) to identify the water quality parameters best correlated to BLM-based WQC. MLR models will be evaluated using standardized statistical procedures[9].

Linear regression is commonly used to derive WQC, such as by EPA in many of its nationally recommended WQC for metals. For example, aquatic life criteria in NMWQS for aluminum, cadmium, chromium, Cu, lead, manganese, nickel, silver and zinc are derived from a simple linear regression using hardness as the independent variable. NMWQS aquatic life criteria for ammonia are based on an MLR equation with temperature and pH as independent variables. In 2018, EPA provided an MLR equation using pH, DOC, and hardness as the basis for their nationally recommended aquatic life criteria for aluminum (EPA 2018a). EPA is also currently evaluating MLRs as the basis of WQC for other metals (EPA 2018b). MLRs have been used by others for describing the effects of water chemistry on bioavailability and toxicity of metals (Rogevich et al. 2008, Erickson et al. 1987, Esbaugh et al. 2012, Fulton and Meyer 2014, and Welsh et al. 1996), including for developing Cu WQC (Brix et al. 2017). The EPA approved an MLR equation for calculating BLM-based SSWQC for a stream in Georgia (Resolve Engineering Inc. 2015, EPA 2016b), consistent with the approach proposed for the Pajarito Plateau surface waters.

Hence, strong scientific and regulatory rationale exists for applying MLRs to account for the effects of water chemistry on metal bioavailability. An MLR equation has the further benefit of being a transparent and readily available option, and with no need for the software, training, and special skills otherwise needed for incorporating EPA 2007 BLM-based Cu WQC into NMWQS as Cu SSWQC for surface waters of the Pajarito Plateau.

In addition to developing a BLM-based MLR equation, application of BLM software for deriving Cu SSWQC will be evaluated. Both approaches will be presented with a discussion of pros/cons in a future Cu SSWQC Technical Report to NMED and EPA. The report will provide recommended Cu SSWQC applicable to the Pajarito Plateau, considering: (1) NMED and EPA comments on the proposed approaches, (2)

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[9] Models may be evaluated using statistical metrics, such as adjusted R^2 values, the Bayesian Information Criterion and the Akaike Information Criterion. Goodness of fit will be further evaluated by comparison of predicted values (e.g., MLR-derived BLM values) versus observed values (e.g., BLM generated WQC), as well as residual analyses of predicted values relative to observed values against independent variables.

implementation considerations, and (3) overall protectiveness to aquatic life resident to surface waters of the Pajarito Plateau.

5 Summary

N3B has developed this WP to initiate a collaborative process with NMED, EPA, and other stakeholders for deriving Cu SSWQC for surface waters of the Pajarito Plateau.

The BLM-based approach described in this WP is consistent with EPA regulations and NMWQS. It represents a significant improvement in setting WQC for aquatic life because it considers additional water chemistry parameters beyond hardness known to have significant effects on the bioavailability and toxicity of Cu. Water chemistry, hydrology, and other characteristics of Pajarito Plateau surface waters are rigorously monitored at a variety of locations under several programs. Furthermore, a DQO/DQA process has already been established for developing an appropriate, site-specific BLM dataset (Windward 2018). For these reasons, the Pajarito Plateau is a suitable setting for deriving BLM-based Cu SSWQC.

An MLR equation, if determined to predict BLM-based Cu SSWQC with reasonable accuracy, may be the most transparent and readily usable option for NMAC adoption. The final recommended approach for Cu SSWQC will be presented in a subsequent Technical Report for review by NMED, EPA, and other stakeholders. The Final Technical Report will provide the technical justification and regulatory rationale for a subsequent Cu SSWQC petition to be taken forward to the NM WQCC. N3B has proposed a preliminary schedule for this rulemaking process and anticipates the schedule may be refined based on comments from NMED and as New Mexico's TR rulemaking schedule is further established.

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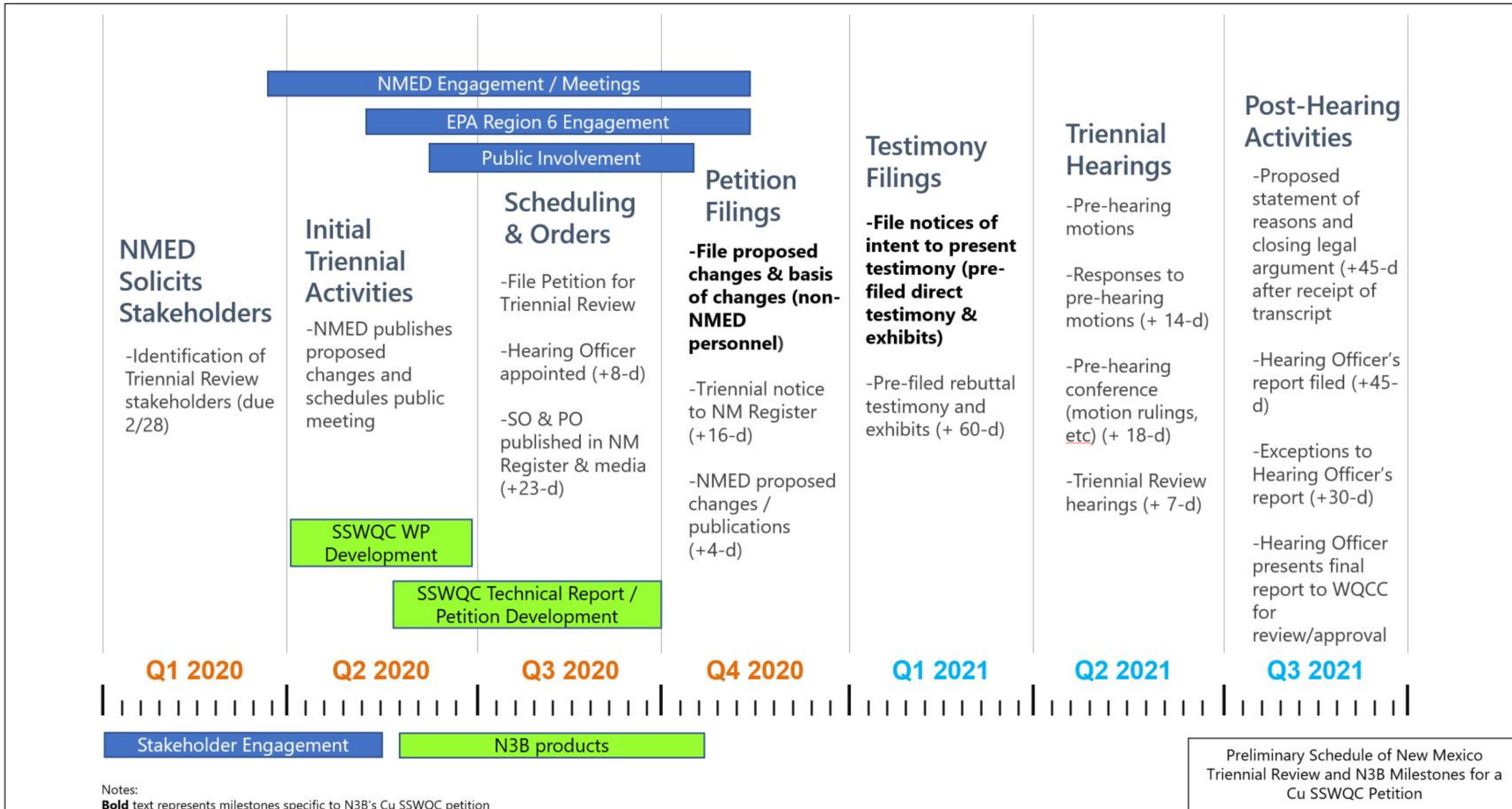

Preliminary Schedule of New Mexico Triennial Review and N3B Milestones for a Cu SSWQC Petition

FIGURE 1

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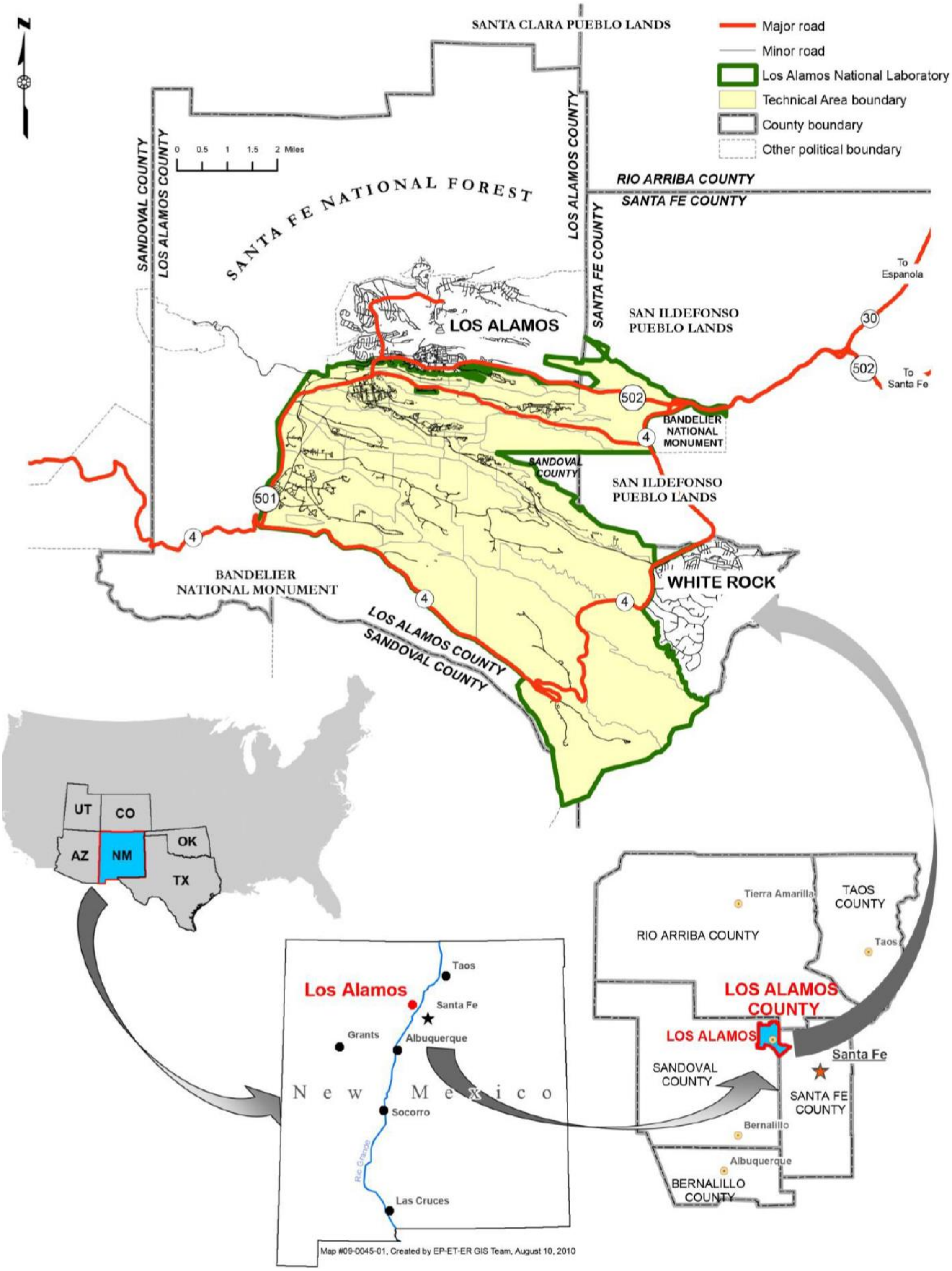

Regional Location of the Laboratory

FIGURE 2

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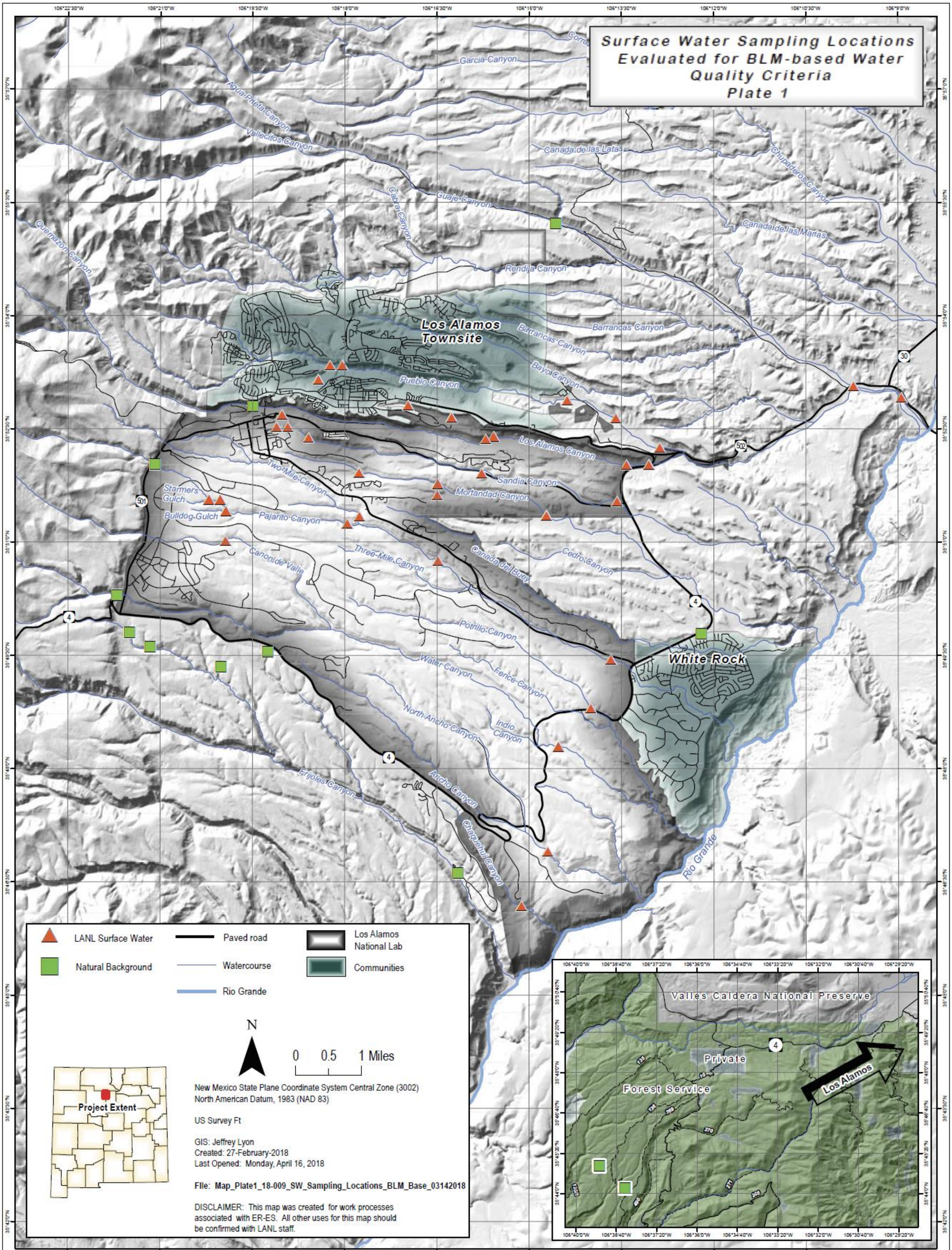

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Figure 3

United States Environmental Protection Agency | Office of Water 4304T | EPA-822-R-07-001 February 2007

AQUATIC LIFE AMBIENT FRESHWATER QUALITY CRITERIA - COPPER

2007 Revision

AQUATIC LIFE AMBIENT FRESHWATER QUALITY CRITERIA - COPPER

2007 Revision

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February 2007

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Office of Water
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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 water-related 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
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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
pH	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 µg/L in surface seawaters and from 0.20 to 30 µg/L in freshwater systems (Bowen, 1985). Copper concentrations in locations receiving anthropogenic inputs can vary anywhere from levels that approach natural background to 100 µg/L or more (e.g., Lopez and Lee, 1977; Nriagu, 1979; Hem, 1989) and have in some cases been reported in the 200,000 µg/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 background, 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 ($Cu{\cdot}nH_2O^{+2}$), 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 toxicity 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 bioavailability provide a reasonable conceptual framework for improved descriptions of how 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 concentration is then multiplied by this ratio (i.e., the WER) to establish a site-specific criterion that reflects the effect of site water characteristics on toxicity. However, a WER accounts only for 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.

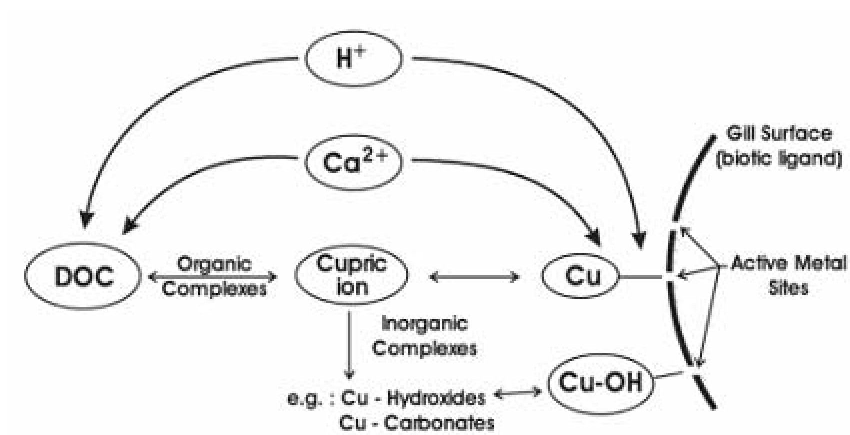

Figure1. Conceptual Diagram of Copper Speciation and Copper-Gill Model (after Pagenkopf, 1983)

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:

$$EC = EC_0 \cdot f_C \cdot f_L \qquad \text{Equation 1}$$

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:

$$EC_0 = \frac{f_{LbT}}{(1 - f_{LbT}) \cdot K_{LbCu}} \qquad \text{Equation 2}$$

$$f_C = 1 + \sum_j^m \left(K_{Cj,Lb} \cdot [C_j]\right) \qquad \text{Equation 3}$$

$$f_L = \frac{1}{\alpha_{Cu^{++}} + \frac{K_{LbCuOH}}{K_{LbCu}} \cdot \alpha_{CuOH}} \qquad \text{Equation 4}$$

where f_{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, α_{Cu+2} is the ratio of free copper concentration to total dissolved copper concentration, α_{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 concentration due to competing cations is simply a sum of the products of their concentrations and binding constants. The increase in the effect concentration due to complexing ligands is the inverse 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:

$$EC_A = EC_B \cdot \frac{f_{C,A} \cdot f_{L,A}}{f_{C,B} \cdot f_{L,B}} \qquad \text{Equation 5}$$

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 α_{Cu+2} and α_{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 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.

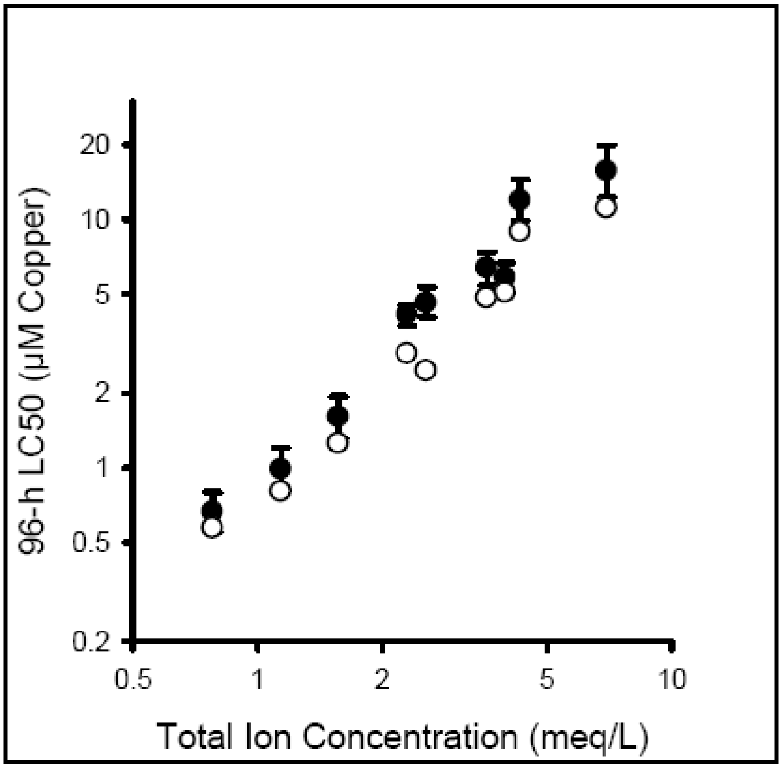

Figure 2. Effects of increasing total ion concentration on the acute lethality of copper to fathead minnows at constant pH=8 and low DOC < 0.5 mg/L. Solid symbols represent observed values, open symbols represent predicted values.

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.

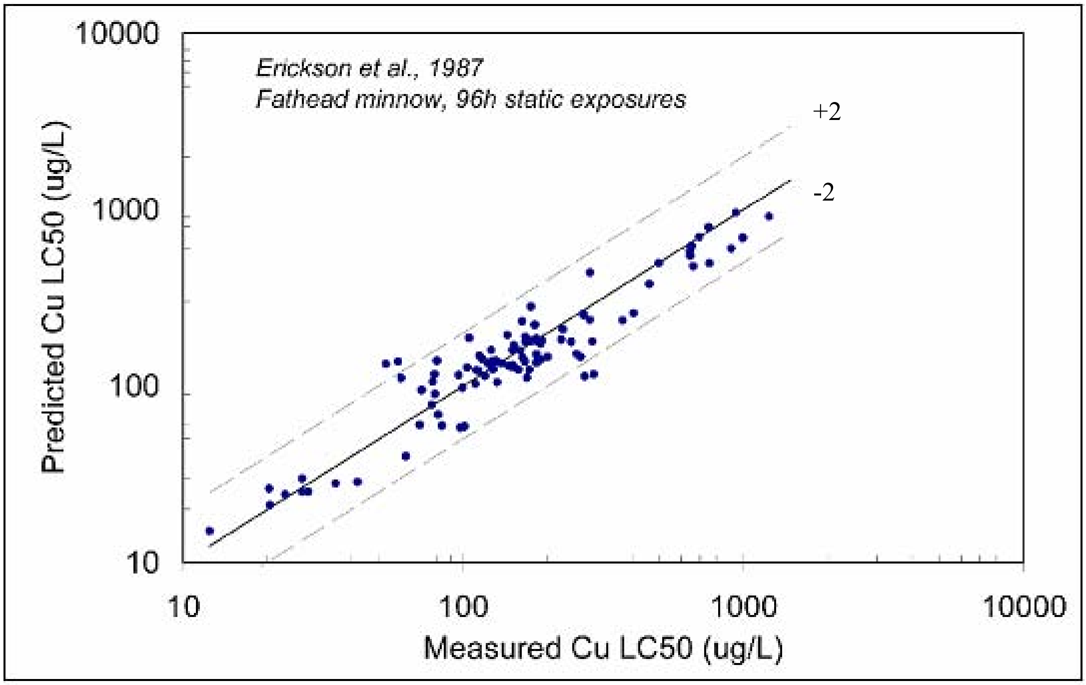

Figure 3. Comparison of Predicted and Measured Acute Copper Toxicity to *P. promelas*.

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_C and f_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:

$$LC50_R = LC50_A \cdot \frac{f_{C,R} \cdot f_{L,R}}{f_{C,A} \cdot f_{L,A}} \qquad \text{Equation 6}$$

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:

$$FAV_B = FAV_R \cdot \frac{f_{C,B} \cdot f_{L,B}}{f_{C,R} \cdot f_{L,R}} \qquad \text{Equation 7}$$

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 = 20ºC, 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_4 =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 4- was 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 µg/L for the most sensitive species, *Daphnia pulicaria*, to 107,860 µg/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 µg/L for *Daphnia* to 107,860 µg/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 µg/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 µg/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

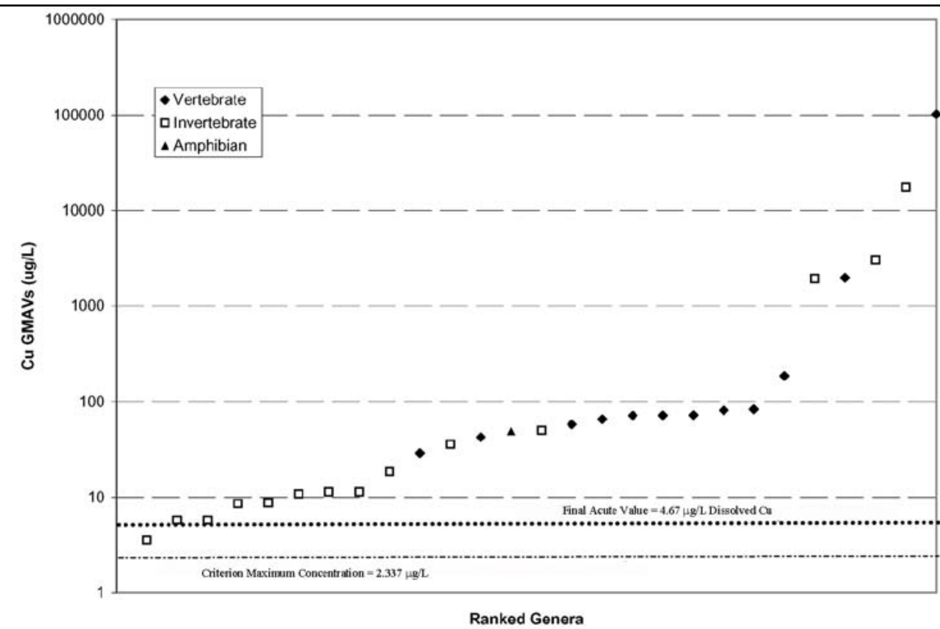

Figure 4. Ranked Freshwater Genus Mean Acute Values (GMAVs)

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 µg/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.

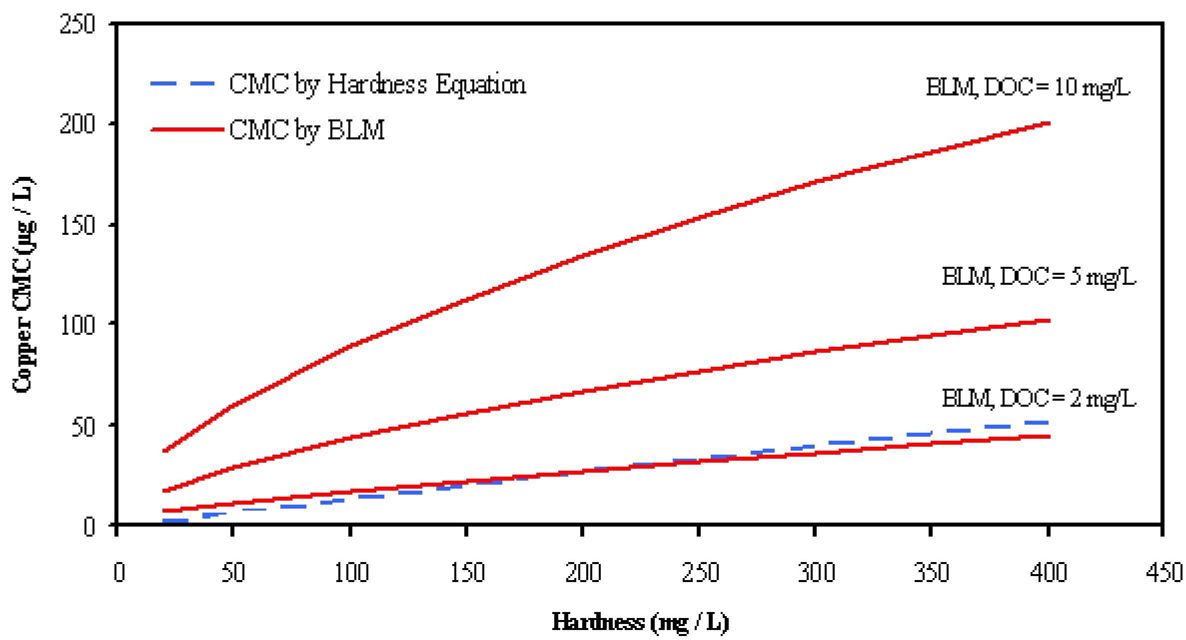

Figure 5. Comparison of CMC calculated by BLM or Hardness Equation Alkalinity (11 - 245 mg CaCO3/L) and pH (7.3 - 8.7) Covary with Hardness

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 equation approaches for waters with a range in pH, hardness, and DOC concentrations. 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 toxicity 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 tested 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 µg/L (*C. dubia*); and the 12 chronic values for the fish species range from <5 (brook trout) to 60.4 µg/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 µg/L, which divided by the FACR of 3.22 results in a freshwater FCV of 1.45 µg/L dissolved Cu.

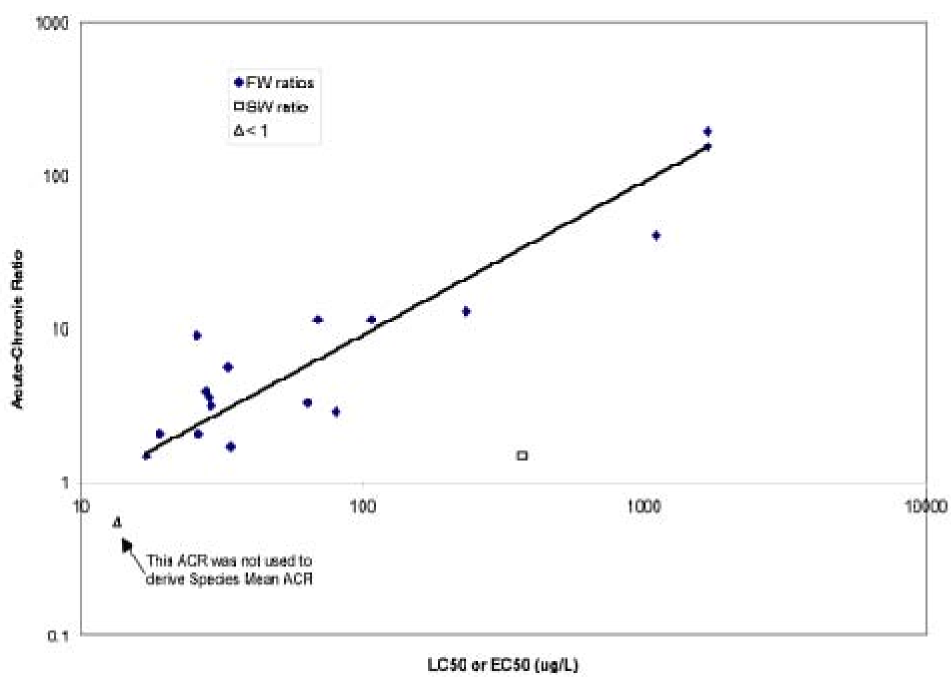

Figure 6. Relationship Between Freshwater Acute Copper Sensitivity (LC50 or EC50) and Acute- Chronic Ratios

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. Notable 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 $CaCO_3$, 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 µg/L copper (mean 2.0 µg/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 µg/L (mean 1.0 µg/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 µg/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 µg/L dissolved copper, the significance of a 1 or 2 µg/L background copper level to a 1 to 3 µg/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 µg/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 mosquitofish 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 µg/L (Koivisto et al., 1992) at an approximate hardness of 25 mg/L (33 mg/L as $CaCO_3$). Yet, example criteria at a hardness of 25 mg/L (as $CaCO_3$) (including those in Figure 6) range from 0.23 µg/L (DOC = 0.1 mg/L) to 4.09 µg/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.

Table 1. Acute Toxicity of Copper to Freshwater Animals

Species[a]	Organism Age, Size, or Lifestage	Method[b]	Chemical[c]	Reported LC50 or EC50 (total µg/L)[d]	Reported LC50 or EC50 (Diss. µg/L)[e]	BLM Data Label	BLM Normalized LC50 or EC50 (µg/L)[f]	Species Mean Acute Value (µg/L)[g]	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, *Juga plicifera*	adult	F,M,T	C	15	---	JUPL01F	12.31	12.31	Nebeker et al. 1986b
Snail, *Lithoglyphus virens*	adult	F,M,T	C	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	N	76	---	UTIM03S	40.96		Keller unpublished
	juvenile	S,M,T	N	85	---	UTIM04S	43.22		Keller unpublished
	juvenile	S,M,T	N	41	---	UTIM05S	24.12		Keller unpublished
	juvenile	S,M,T	S	79	---	UTIM06S	39.04		Keller unpublished
	juvenile	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	C	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

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Species[a]	Organism Age, Size, or Lifestage	Method[b]	Chemical[c]	Reported LC50 or EC50 (total µg/L)[d]	Reported LC50 or EC50 (Diss. µg/L)[e]	BLM Data Label	BLM Normalized LC50 or EC50 (µg/L)[f]	Species Mean Acute Value (µg/L)[g]	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	C	9.1	---	DAMA01S	3.42	6.00	Nebeker et al. 1986a
Daphnia magna	1 d	S,M,T	C	11.7	---	DAMA02S	4.43		Nebeker et al. 1986a
	<2 h	S,M,T	C	6.6	---	DAMA03S	2.50		Nebeker et al. 1986a
	<2 h	S,M,T	C	9.9	---	DAMA04S	3.78		Nebeker et al. 1986a
	1 d	S,M,T	C	11.7	---	DAMA05S	13.46		Nebeker et al. 1986a
	<4 h	S,M,T	C	6.7	---	DAMA06S	8.21		Nebeker et al. 1986a
	1 d	S,M,T	C	9.1	---	DAMA07S	4.40		Nebeker et al. 1986a
	<2 h	S,M,T	C	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)
	---	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)

Table 1. Acute Toxicity of Copper to Freshwater Animals

Species[a]	Organism Age, Size, or Lifestage	Method[b]	Chemical[c]	Reported LC50 or EC50 (total µg/L)[d]	Reported LC50 or EC50 (Diss. µg/L)[e]	BLM Data Label	BLM Normalized LC50 or EC50 (µg/L)[f]	Species Mean Acute Value (µg/L)[g]	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	C	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	N	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, *Chironomus*	4th instar	S,M,T	S	739	---	CHDE01S	1987	1987	Kosalwat and Knight 1987
Shovelnose sturgeon, *Scaphirhynchus*	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

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Species[a]	Organism Age, Size, or Lifestage	Method[b]	Chemical[c]	Reported LC50 or EC50 (total µg/L)[d]	Reported LC50 or EC50 (Diss. µg/L)[e]	BLM Data Label	BLM Normalized LC50 or EC50 (µg/L)[f]	Species Mean Acute Value (µg/L)[g]	Reference
Cutthroat trout,	7.4 cm, 4.2 g	F,M,T,D	C	398.91	367	ONCL03F	67.30		Chakoumakos et al. 1979
Oncorhynchus clarki	6.9 cm, 3.2 g	F,M,T,D	C	197.87	186	ONCL04F	44.91		Chakoumakos et al. 1979
	8.8 cm, 9.7 g	F,M,T,D	C	41.35	36.8	ONCL05F	21.87		Chakoumakos et al. 1979
	8.1 cm, 4.4 g	F,M,T,D	C	282.93	232	ONCL06F	51.94		Chakoumakos et al. 1979
	6.8 cm, 2.7 g	F,M,T,D	C	186.21	162	ONCL07F	111.3		Chakoumakos et al. 1979
	7.0 cm, 3.2 g	F,M,T,D	C	85.58	73.6	ONCL08F	39.53		Chakoumakos et al. 1979
	8.5 cm, 5.2 g	F,M,T,D	C	116.67	91	ONCL09F	19.63		Chakoumakos et al. 1979
	7.7 cm, 4.4 g	F,M,T,D	C	56.20	44.4	ONCL10F	18.81		Chakoumakos et al. 1979
	8.9 cm, 5.7 g	F,M,T,D	C	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 gorbu	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 kisutc	parr	F,M,T	C	33	---	ONKI02F	20.94		Chapman 1975
	adult, 2.7 kg	F,M,T	C	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	C	46.7	40	ONMY04R	10.90		Cacela et al. 1996
	swim-up, 0.25 g	R,M,T,D	C	24.2	19	ONMY05R	9.04		Cacela et al. 1996
	swim-up, 0.20-0.24 g	R,M,T,D	C	0	3.4	ONMY06R	5.02		Welsh et al. 2000
	swim-up, 0.20-0.24 g	R,M,T,D	C	0	8.1	ONMY07R	11.97		Welsh et al. 2000
	swim-up, 0.20-0.24 g	R,M,T,D	C	0	17.2	ONMY08R	13.80		Welsh et al. 2000
	swim-up, 0.20-0.24 g	R,M,T,D	C	0	32	ONMY09R	23.84		Welsh et al. 2000
	alevin	F,M,T	C	28	---	ONMY10F	20.30		Chapman 1975, 1978
	swim-up, 0.17 g	F,M,T	C	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
	smolt, 18.8 cm, 68.19	F,M,T	C	29	---	ONMY13F	22.48		Chapman 1975, 1978
	1 g	F,M,T,D	C	-	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	C	-	83.3	ONMY16F	9.93		Chakoumakos et al. 1979
	6.1 cm, 2.5 g	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 g	F,M,T,D	C	-	128	ONMY19F	16.51		Chakoumakos et al. 1979
	9.2 cm, 9.4 g	F,M,T,D	C	-	221	ONMY20F	33.33		Chakoumakos et al. 1979
	9.9 cm, 11.5 g	F,M,T,D	C	-	165	ONMY21F	22.70		Chakoumakos et al. 1979
	11.8 cm, 18.7 g	F,M,T,D	C	-	197	ONMY22F	28.60		Chakoumakos et al. 1979
	13.5 cm, 24.9 g	F,M,T,D	C	-	514	ONMY23F	99.97		Chakoumakos et al. 1979

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	13.4 cm, 25.6 g	F,M,T,D	C	-	243	ONMY24F	37.88		Chakoumakos et al. 1979
	6.7 cm, 2.65 g	F,M,T	C	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	C	19.6	18	ONMY27F	8.10		Cacela et al. 1996
	swim-up, 0.25 g	F,M,T,D	C	12.9	12	ONMY28F	32.15		Cacela et al. 1996
	swim-up, 0.23 g	F,M,T,D	C	5.9	5.7	ONMY29F	24.80		Cacela et al. 1996
	swim-up, 0.23 g	F,M,T,D	C	37.8	35	ONMY30F	16.16		Cacela et al. 1996
	swim-up, 0.26 g	F,M,T,D	C	25.1	18	ONMY31F	37.66		Cacela et al. 1996
	swim-up, 0.23 g	F,M,T,D	C	17.2	17	ONMY32F	24.19		Cacela et al. 1996
	0.64 g, 4.1 cm	F,M,T,D	C	101	---	ONMY33F	39.73		Hansen et al. 2000
	0.35 g, 3.4 cm	F,M,T,D	C	308	---	ONMY34F	85.83		Hansen et al. 2000
	0.68 g, 4.2 cm	F,M,T,D	C	93	---	ONMY35F	95.9		Hansen et al. 2000
	0.43 g, 3.7 cm	F,M,T,D	C	35.9	---	ONMY36F	50.83		Hansen et al. 2000
	0.29 g, 3.4 cm	F,M,T,D	C	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	C	26	---	ONTS01F	14.48	25.02	Chapman 1975, 1978
Oncorhynchus tshaw	swim-up, 0.23 g	F,M,T	C	19	---	ONTS02F	10.44		Chapman 1975, 1978
	parr, 9.6 cm, 11.58 g	F,M,T	C	38	---	ONTS03F	28.30		Chapman 1975, 1978
	smolt, 14.4 cm, 32.46	F,M,T	C	26	---	ONTS04F	20.09		Chapman 1975, 1978
	3 mo, 1.35 g	F,M,T,I	C	10.2	---	ONTS05F	19.41		Chapman and McCrady 1977
	3 mo, 1.35 g	F,M,T,I	C	24.1	---	ONTS06F	30.91		Chapman and McCrady 1977
	3 mo, 1.35 g	F,M,T,I	C	82.5	---	ONTS07F	32.74		Chapman and McCrady 1977
	3 mo, 1.35 g	F,M,T,I	C	128.4	---	ONTS08F	20.66		Chapman and McCrady 1977
	swim-up, 0.36-0.45 g	F,M,T,D	C	0	7.4	ONTS09F	36.49		Welsh et al. 2000
	swim-up, 0.36-0.45 g	F,M,T,D	C	0	12.5	ONTS10F	30.85		Welsh et al. 2000
	swim-up, 0.36-0.45 g	F,M,T,D	C	0	14.3	ONTS11F	31.49		Welsh et al. 2000
	swim-up, 0.36-0.45 g	F,M,T,D	C	0	18.3	ONTS12F	48.56		Welsh et al. 2000

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Bull trout, *Salvelinus confluenti*	0.130 g, 2.6 cm	F,M,T,D	C	228	---	SACO01F	69.70	68.31	Hansen et al. 2000
	0.555 g, 4.0 cm	F,M,T,D	C	207	---	SACO02F	63.62		Hansen et al. 2000
	0.774 g, 4.5 cm	F,M,T,D	C	66.6	---	SACO03F	74.18		Hansen et al. 2000
	1.520 g, 5.6 cm	F,M,T,D	C	50	---	SACO04F	63.60		Hansen et al. 2000
	1.160 g, 5.2 cm	F,M,T,D	C	89	---	SACO05F	71.11		Hansen et al. 2000
Chiselmouth, *Acrocheilus*	4.6 cm, 1.25 g	F,M,T	C	143	---	ACAL01F	216.3	216.3	Andros and Garton 1980
Bonytail chub, *Gila elegans*	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	C	84600	---	NOCR01F	107860	107860	Hartwell et al. 1989
Fathead minnow, *Pimephales promela*	adult, 40 mm	S,M,T	S	310	---	PIPR01S	266.3	69.63	Birge et al. 1983
	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	C	55	---	PIPR04S	38.08		Carlson et al. 1986
	---	S,M,T	C	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,T	N	>200	---	PIPR08S	24.38		Schubauer-Berigan et al. 1993
	<24 h, 0.68 mg	S,M,T	S	4.82	---	PIPR09S	8.87		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	8.2	---	PIPR10S	16.72		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	31.57	---	PIPR11S	25.15		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	21.06	---	PIPR12S	17.67		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	35.97	---	PIPR13S	21.24		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	59.83	---	PIPR14S	16.64		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	4.83	---	PIPR15S	5.92		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	70.28	---	PIPR16S	13.34		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	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		Dwyer et al. 1995
	larval, 0.56 g	S,M,T	S	630	---	PIPR20S	157.9		Dwyer 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
	3.2-5.5 cm, 0.42-3.23	S,M,T	S	450	---	PIPR23S	152.9		Richards and Beitinger 1995
	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
	3.0-4.8 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

Table 1. Acute Toxicity of Copper to Freshwater Animals

Species[a]	Organism Age, Size, or Lifestage	Method[b]	Chemical[c]	Reported LC50 or EC50 (total µg/L)[d]	Reported LC50 or EC50 (Diss. µg/L)[e]	BLM Data Label	BLM Normalized LC50 or EC50 (µg/L)[f]	Species Mean Acute Value (µg/L)[g]	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

Table 1. Acute Toxicity of Copper to Freshwater Animals

Species[a]	Organism Age, Size, or Lifestage	Method[b]	Chemical[c]	Reported LC50 or EC50 (total µg/L)[d]	Reported LC50 or EC50 (Diss. µg/L)[e]	BLM Data Label	BLM Normalized LC50 or EC50 (µg/L)[f]	Species Mean Acute Value (µg/L)[g]	Reference
Northern squawfish,	5.0 cm, 1.33 g	F,M,T	C	23	---	PTOR01F	17.02	14.61	Andros and Garton 1980
Ptychocheilus orego	7.2 cm, 3.69 g	F,M,T	C	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	C	-	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	C	1000	---	LEMA03F	4200		Cairns et al. 1981
	3.58 cm, 0.63 g	F,M,D	C	-	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, *Etheostoma rubrum*	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

[a] 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.

[b] 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.

[d] Values in this column are total copper LC50 or EC50 values as reported by the author.

[e] 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.

[f] Normalization Chemistry

Temp	pH	Diss Cu	DOC	%HA	Ca	Mg	Na	K	SO_4	Cl	Alkalinity	S
Deg C		ug/L	mg/L		mg/L	mg/L	mg/L	mg/L	mg/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.

* Table updated as of March 2, 2007

Table 2a. Chronic Toxicity of Copper to Freshwater Animals

Species	Test[a]	Chemical	Endpoint	Hardness (mg/L as CaCO3)	Chronic Limits (µg/L)	Chronic Values		Species Mean Chronic Value (Total µg/L)	Genus Mean Chronic Value (Total µg/L)	ACR	Reference
						Chronic Value[b] (µg/L)	EC20[b] (µg/L)				
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[c] (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[c] (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

Table 2a. Chronic Toxicity of Copper to Freshwater Animals

Species	Test[a]	Chemical	Endpoint	Hardness (mg/L as CaCO3)	Chronic Limits (µg/L)	Chronic Values: Chronic Value[b] (µg/L)	Chronic Values: EC20[b] (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, *Esox lucius*	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

[a] LC = life-cycle; PLC = partial life-cyle; ELS = early life state; T = total copper; D = dissolved copper.

[b] Results are based on copper, not the chemical.

[c] 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 $CaCO_3$)	Acute Value (µg/L)	Chronic Value (µg/L)	Ratio	Reference	Overall Ratio for Species	
Snail,	35-55	1673[a]	8.73	191.61	Arthur and Leonard 1970		
Campeloma decisum	35-55	1673[a]	10.94	152.95	Arthur and Leonard 1970	171.19	
Cladoceran,	[redacted]	28.42[b]	7.90	3.60	[redacted]		
Ceriodaphnia dubia	[redacted]	63.33[b]	19.36	3.27	[redacted]		
	57	13.4	24.5	0.55	Oris et al. 1991		
	--	[redacted]	9.17	1.96	[redacted]	2.85[g]	✓
Cladoceran,	51	26	12.58	2.07	Chapman et al. Manuscript		
Daphnia magna	104	33.76[d]	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	[redacted]		
Daphnia pulex	115	27.6	7.07	3.90	[redacted]		
	230	28.79	9.16	3.14	[redacted]	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[e]	18	12.88	Horning and Neiheisel 1979	12.88	
Fathead minnow, *Pimephales promelas*	45	106.875[f]	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	✓

[a]Geometric mean of two values from Arthur and Leonard (1970) in Table 1.

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

[c]Geometric mean of two values from Carlson et al. (1986) in Table 1.

[d]Geometric mean of two values from Chapman manuscript in Table 1.

[e]Geometric mean of two values of three values from Horning and Neiheisel (1979) in Appendix C.

[f]Geometric mean of three values from Lind et al. (1978) in Table 1.

[g]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 updated as of March 2, 2007

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, *Campeloma decisum*	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, *Gila elegans*	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, *Bufo boreas*	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, *Physa integra*	20.41	
8	12.31	Snail, *Juga plicifera*	12.31	
7	12.07	Amphipod, *Hyalella azteca*	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, *Lithoglyphus virens*	6.67	
2	5.93	Cladoceran, *Ceriodaphnia dubia*	5.93	2.85
1	4.05	Cladoceran, *Daphnia magna*	6.00	3.42
		Cladoceran, *Daphnia pulicaria*	2.73	

* Table updated as of March 2, 2007

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	lnGMAV	$(lnGMAV)^2$	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 =	4.374				
L =	0.5641				
A =	1.542				
Calculated FAV =	**4.674452**				
Calculated CMC =	**2.337**				

Dissolved Copper Criterion Maximum Concentration (CMC) = 2.337 µg/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 µg/L (for example normalization chemistry see Table 1, footnote f)

S = Scale parameter or slope
L = Location parameter or intercept
P = Cumulative probability
A = lnFAV

* Table updated as of March 2, 2007

Table 4. Toxicity of Copper to Freshwater Plants

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result[b] (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, *Anabaena* 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

Table 4. Toxicity of Copper to Freshwater Plants

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result[b] (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, *Lemna minor*	S,U	Copper sulfate	-	28 days	Significant plant damage	130	Brown and Rattigan 1979

Table 4. Toxicity of Copper to Freshwater Plants

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result[b] (Total µg/L)	Reference
Duckweed, *Lemna minor*	S,U	-	0	96 hr	EC50 (frond number)	1,100	Wang 1986
Duckweed, *Lemna minor*	S,U	Copper sulfate	78	96 hr	EC50 (chlorophyll a reduction)	250	Eloranta et al. 1988
Duckweed, *Lemna minor*	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

[a] S=Static; R=Renewal; F=Flow-through; M=Measured; U=Unmeasured; T=Total metal conc. measured; D=dissolved metal conc. measured.

[b] Results are expressed as copper, not as the chemical.

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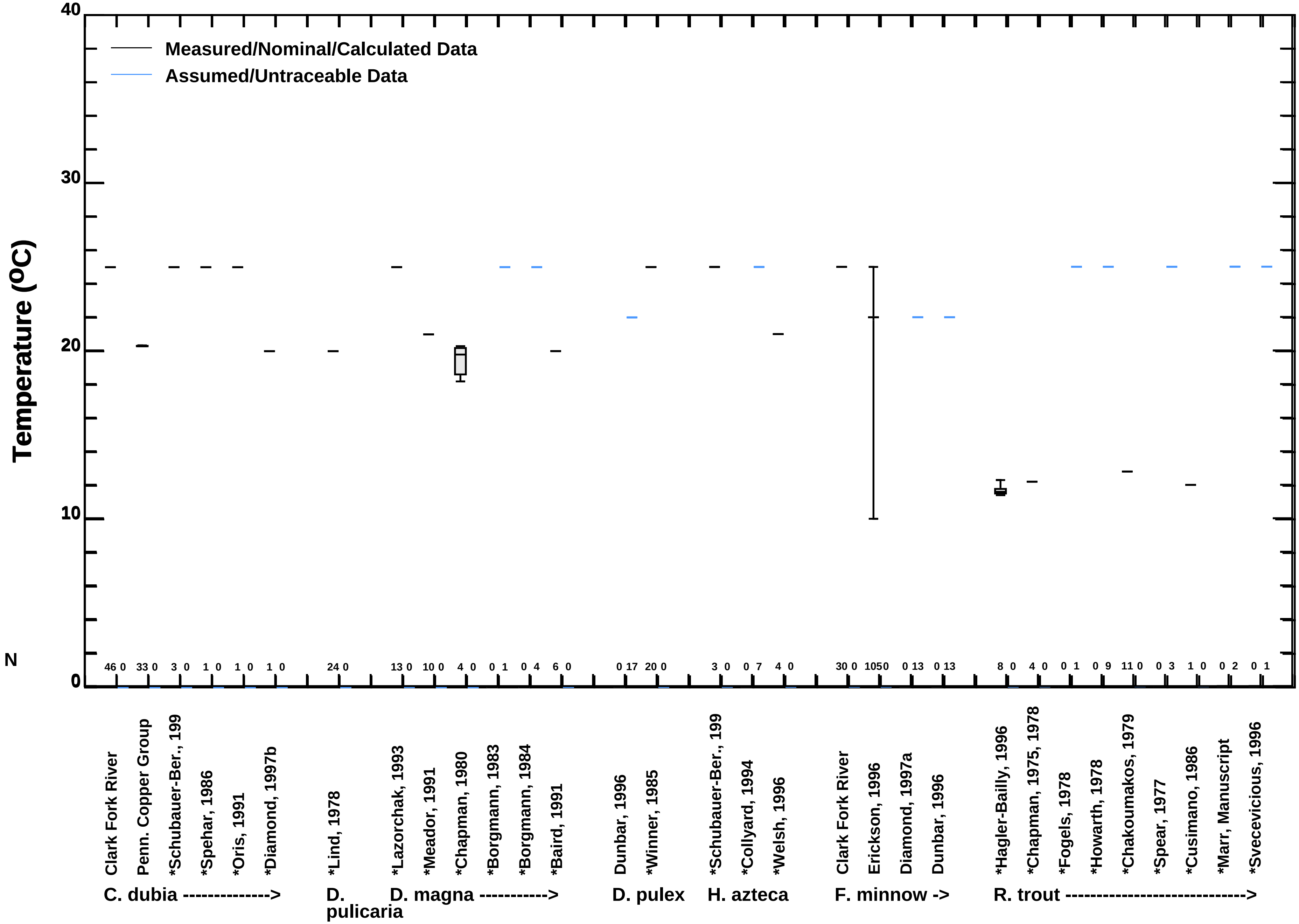
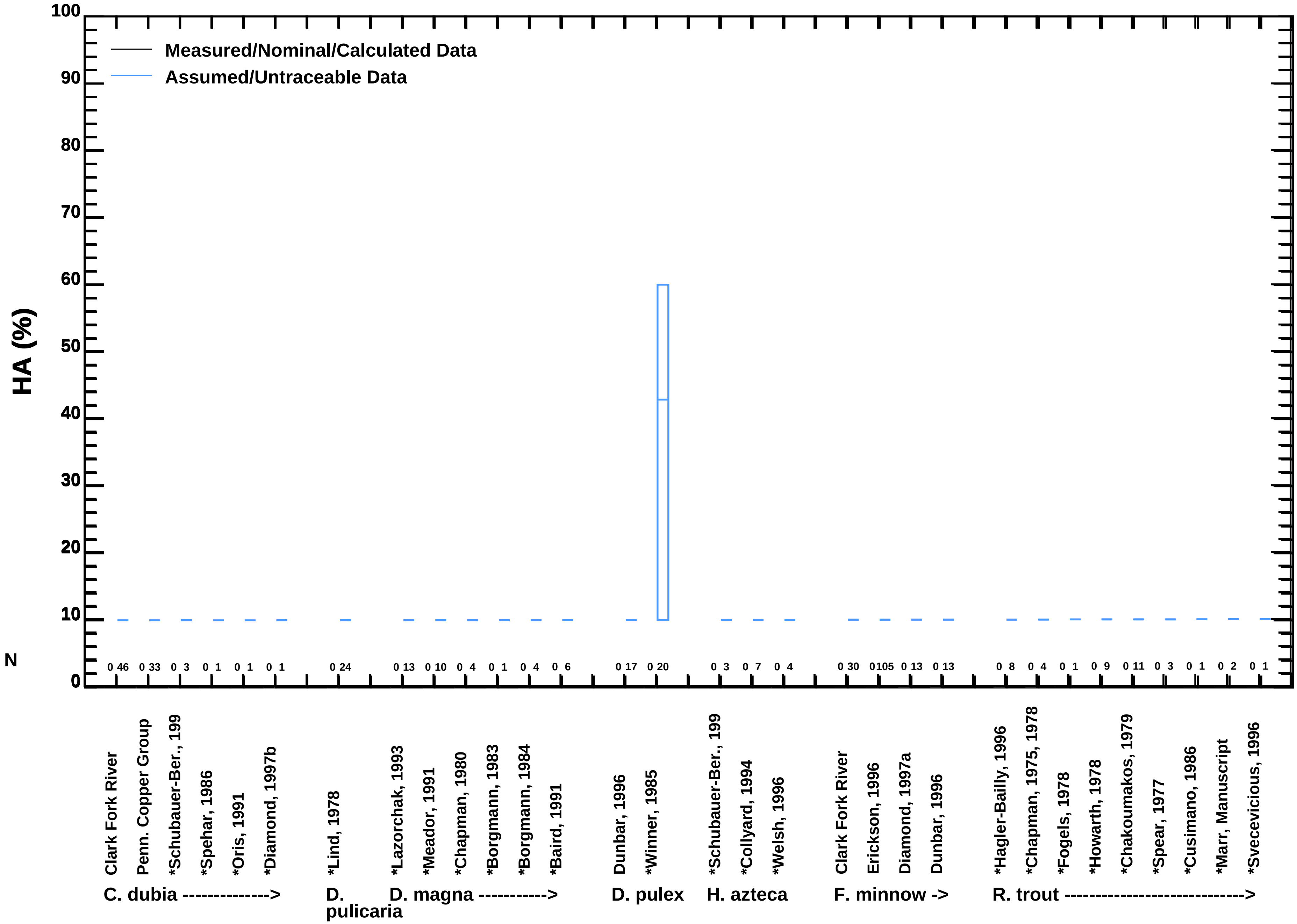
Appendices

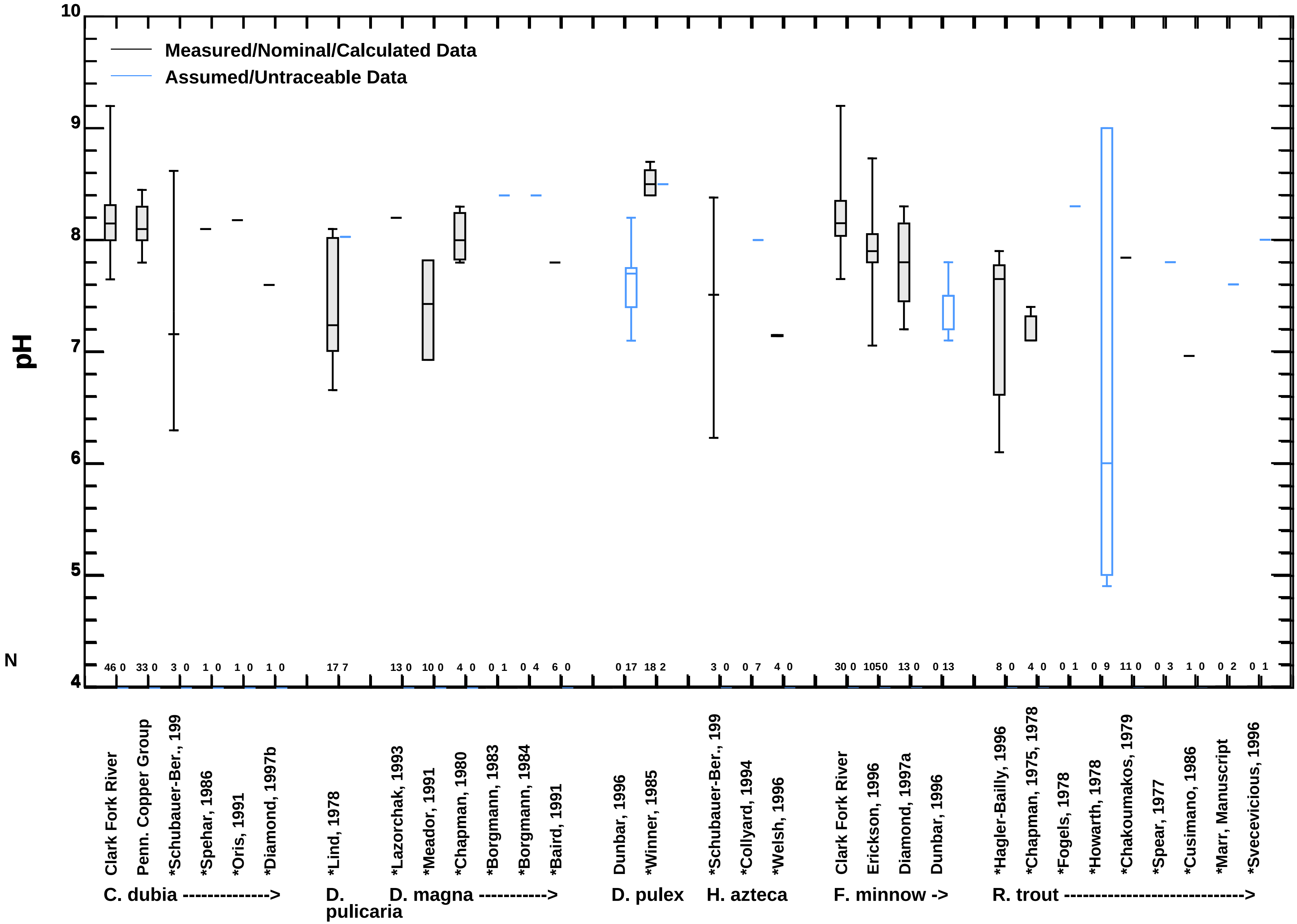
Appendix A. Ranges in Calibration and Application Data Sets



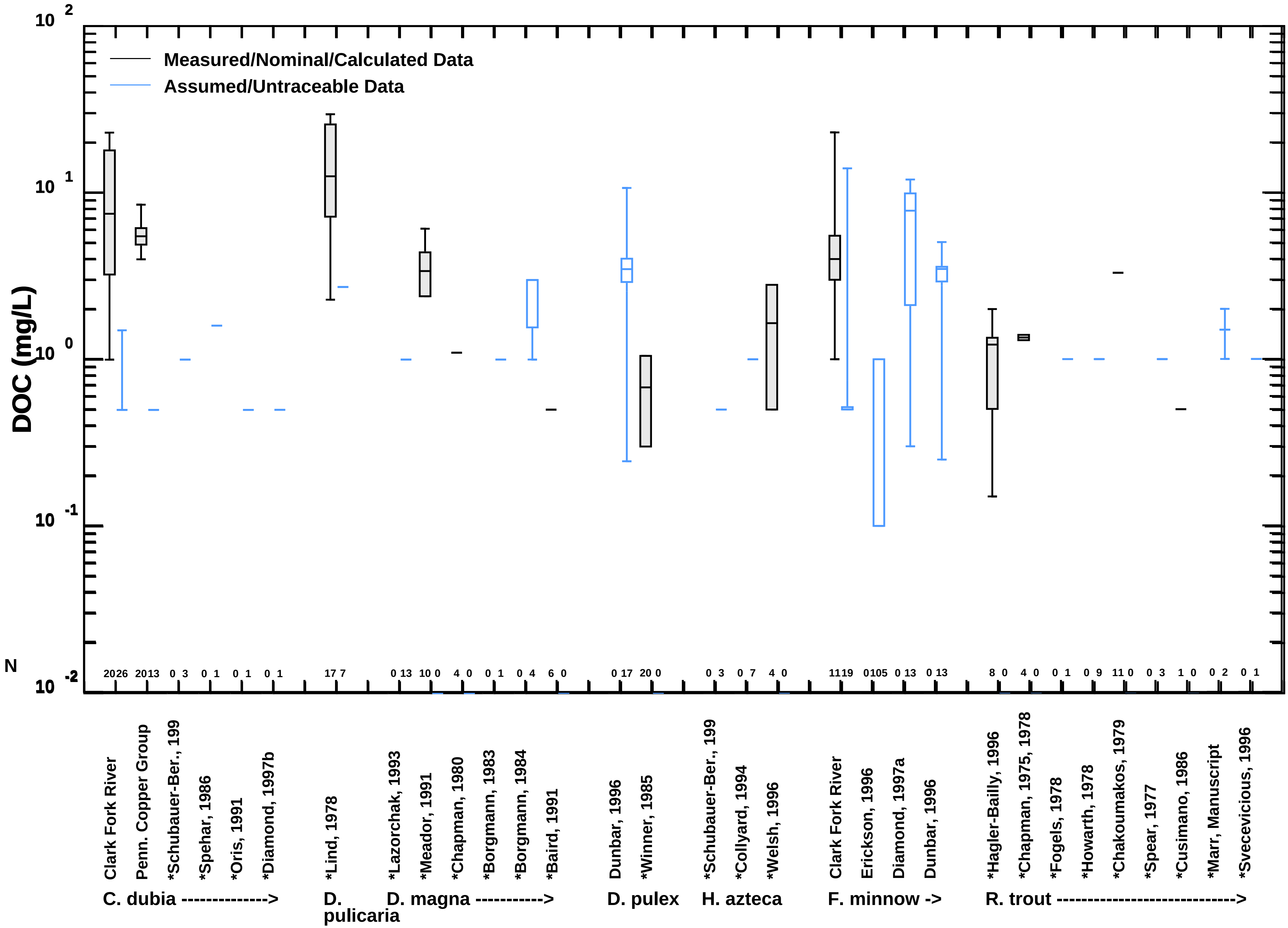
Median, Range and Quartiles of Temperature in BLM Calibration and Application Datasets
(All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)



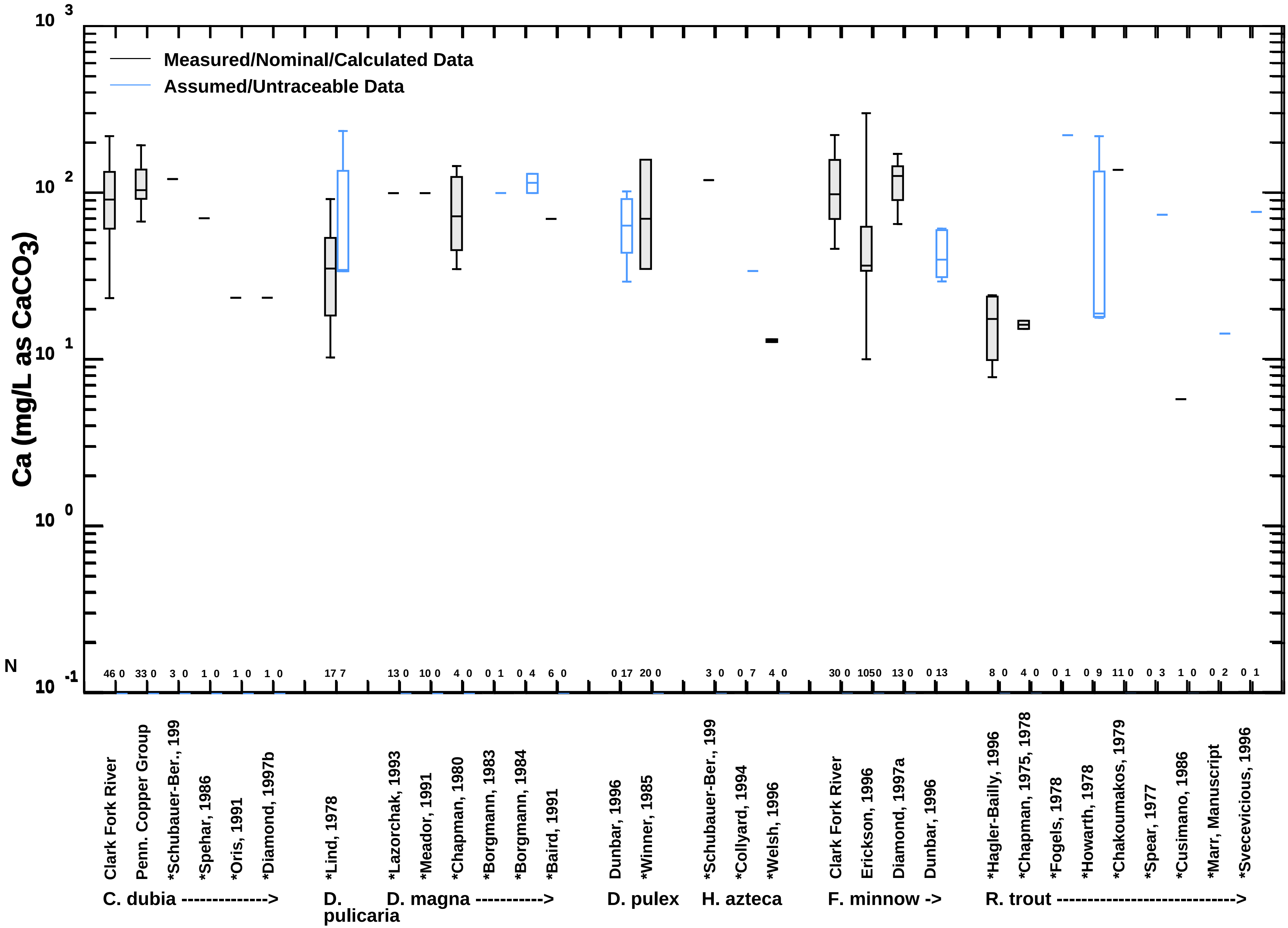
Median, Range and Quartiles of HA in BLM Calibration and Application Datasets
(All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)



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)

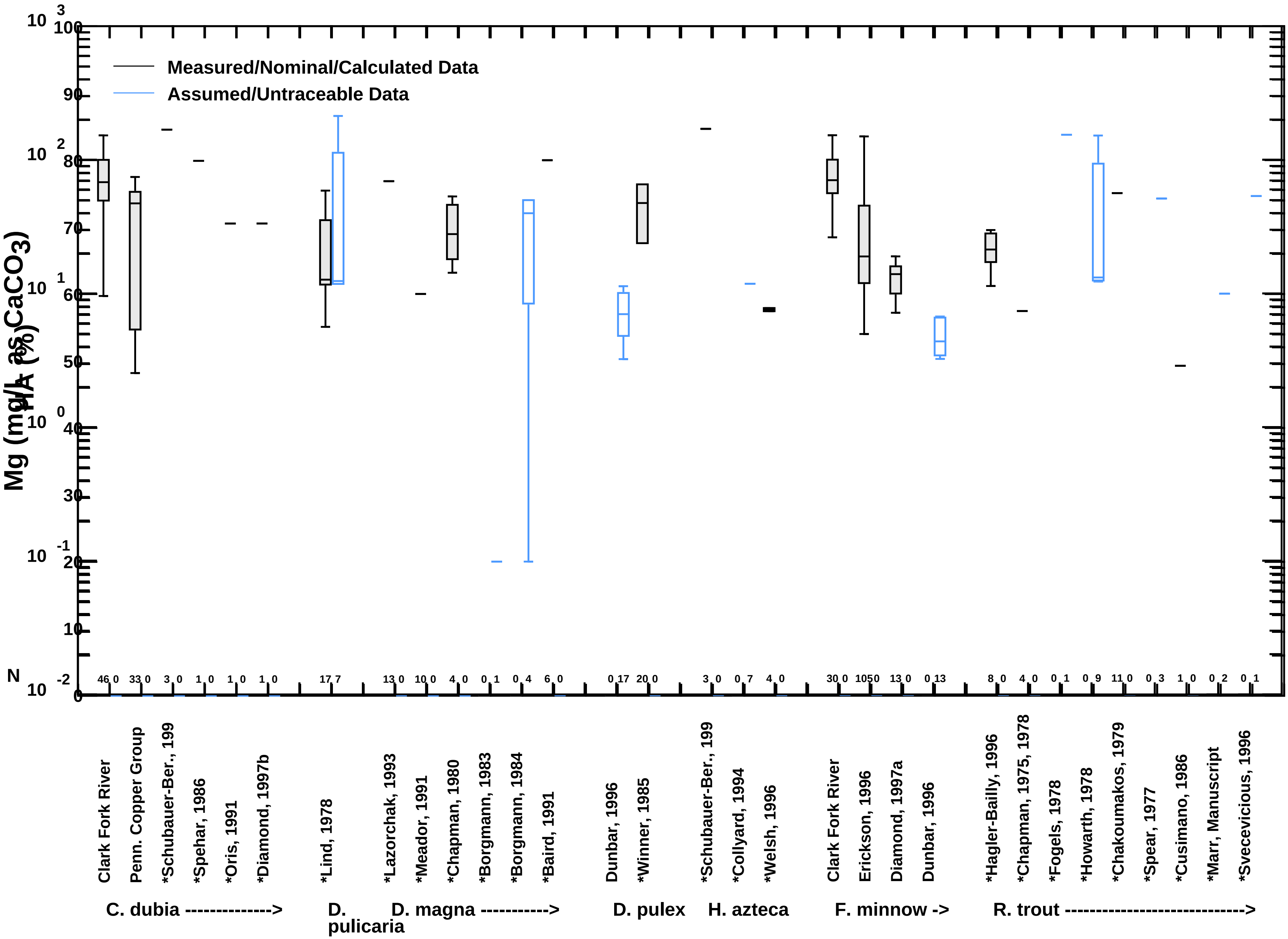


Median, Range and Quartiles of DOC in BLM Calibration and Application Datasets
(All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)



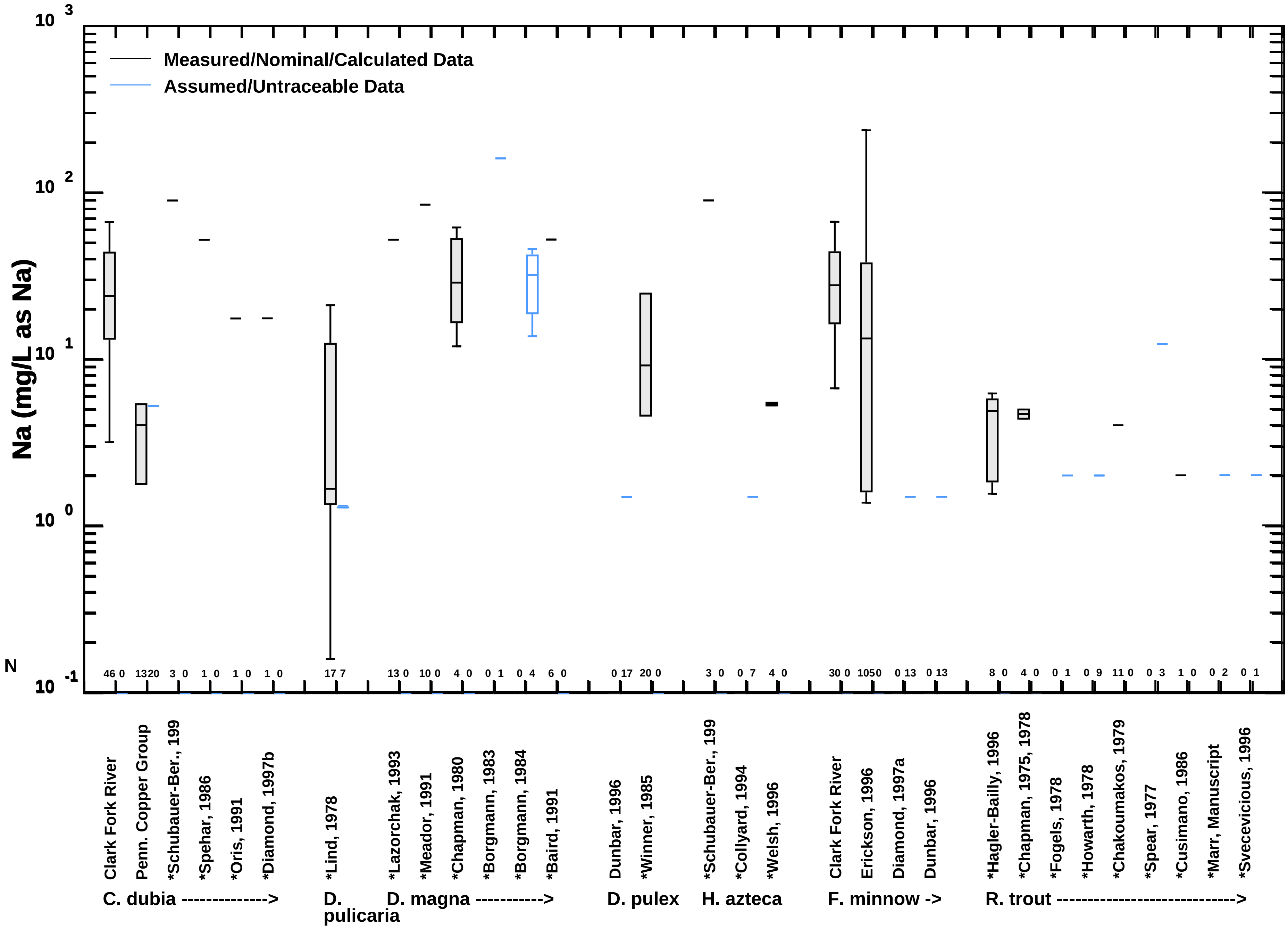
Median, Range and Quartiles of Ca in BLM Calibration and Application Datasets
(All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)

Petitioners_0559

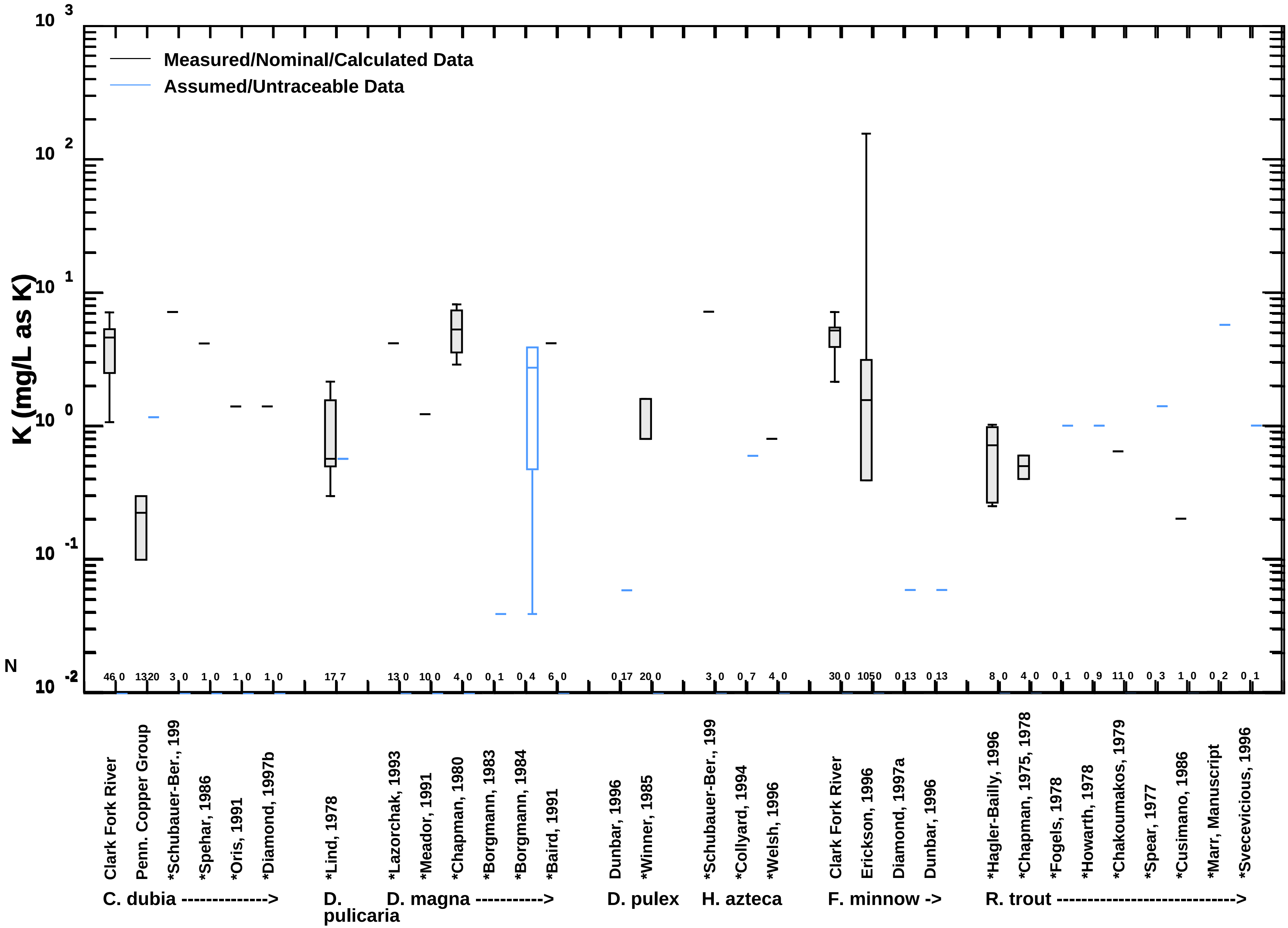


Median, Range and Quartiles of HA in BLM Calibration and Application Datasets
(All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)

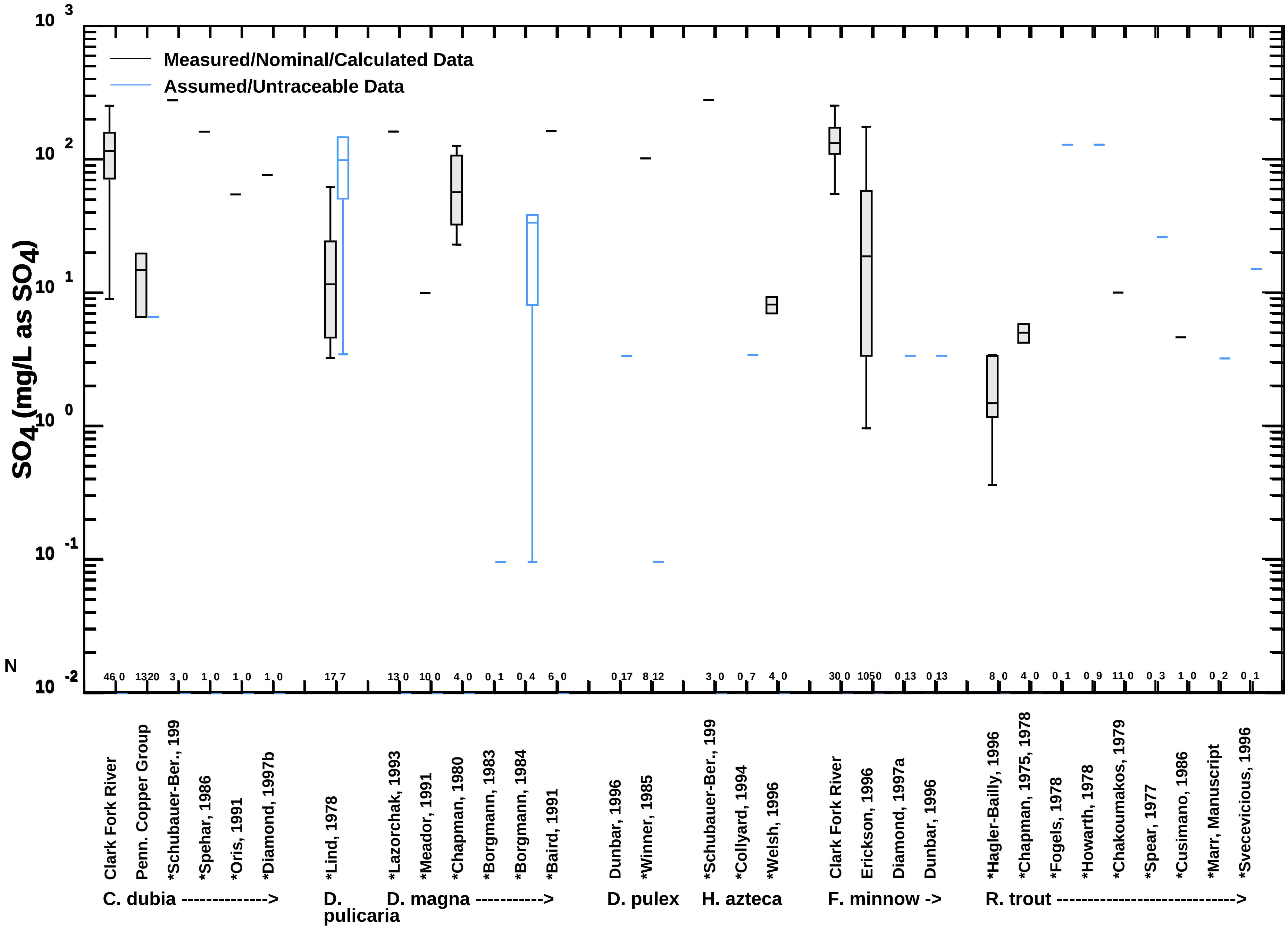
Petitioners_0560



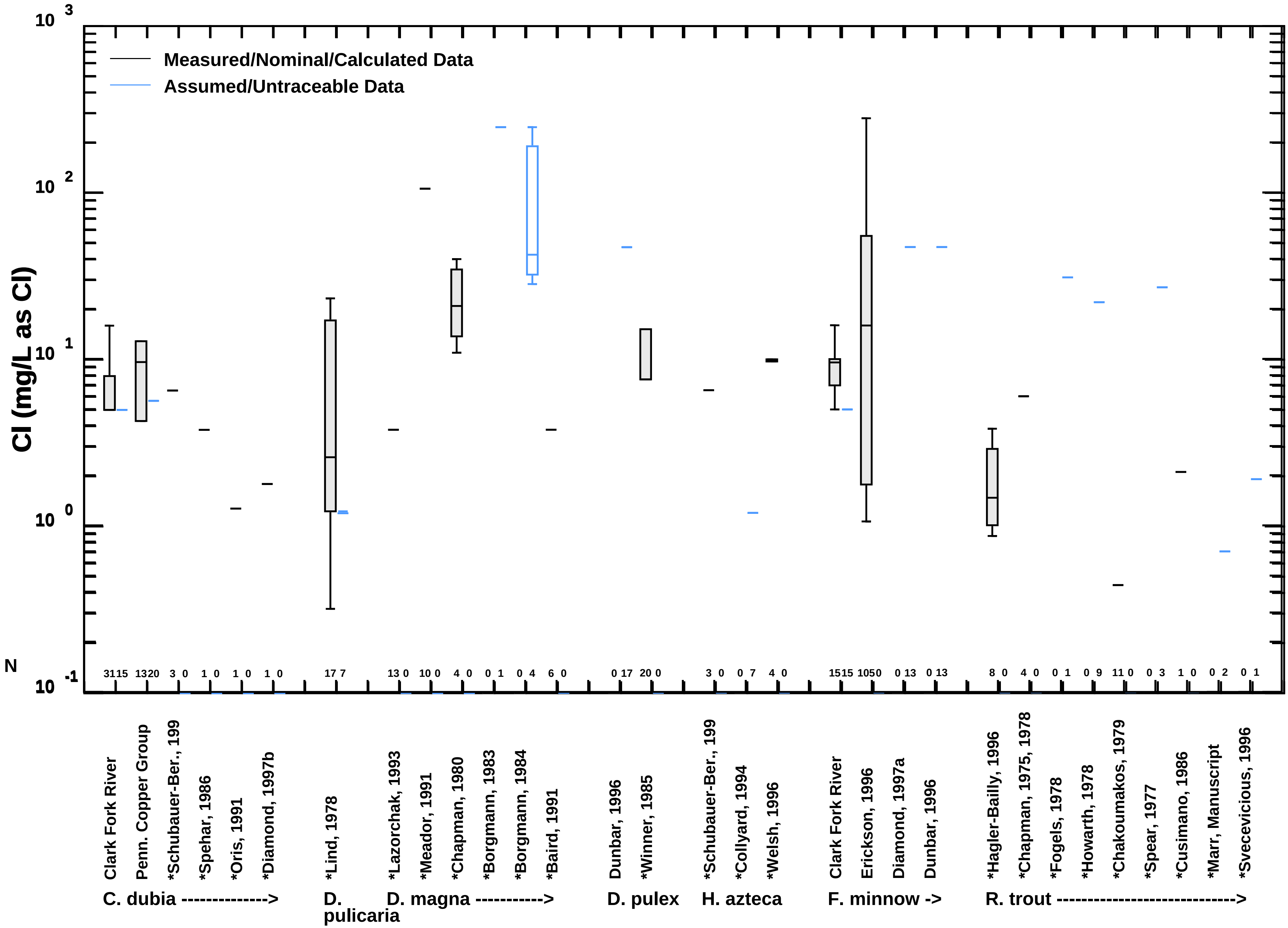
Median, Range and Quartiles of Na in BLM Calibration and Application Datasets
(All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)



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)

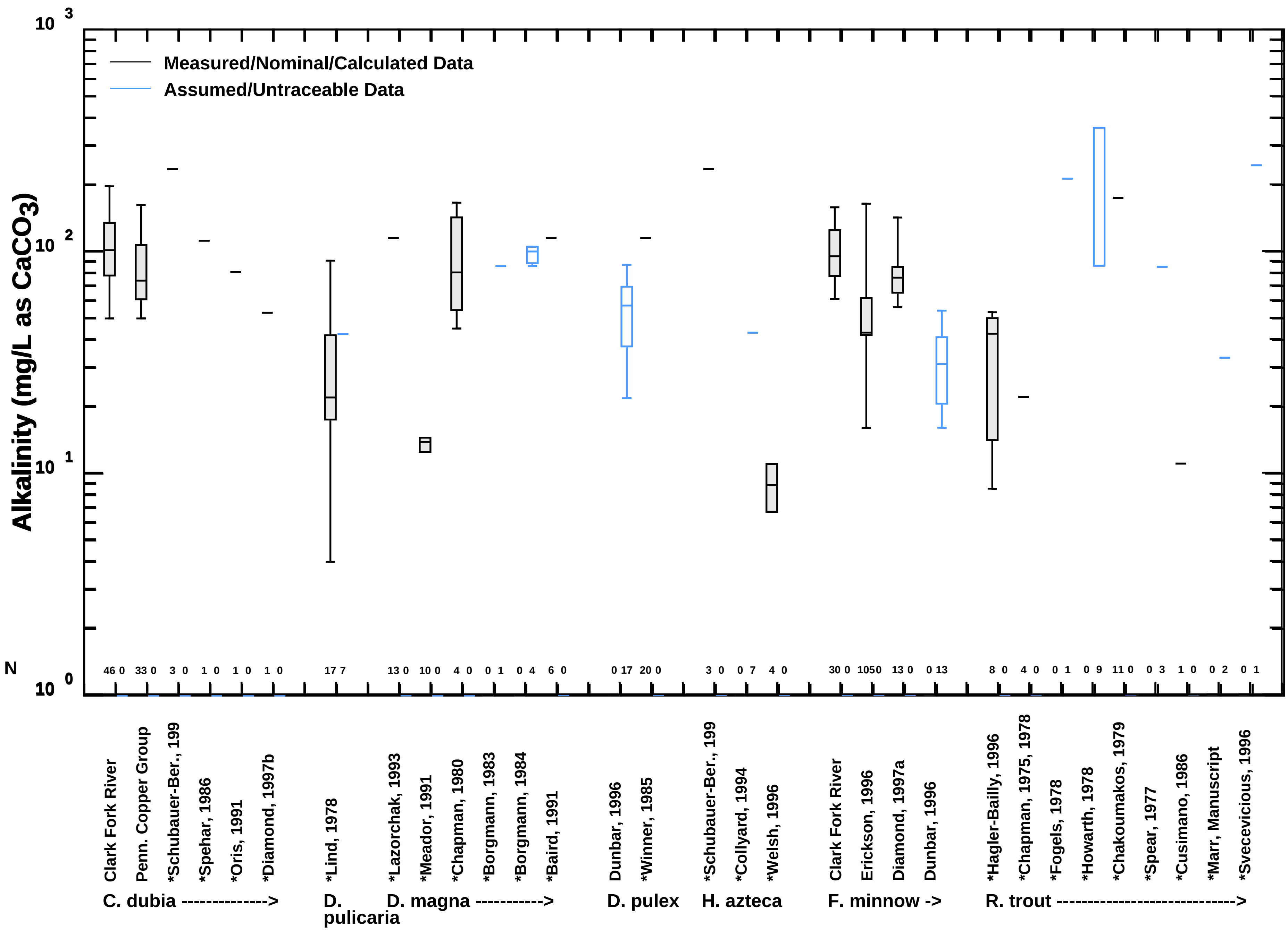


Median, Range and Quartiles of SO4 in BLM Calibration and Application Datasets
(All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)



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

Petitioners_0564



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)

Appendix B. Other Data on Effects of Copper on Freshwater Organisms

Appendix B. Other Data on Effects of Copper on Freshwater Organisms

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	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, *Entosiphon sulcatum*	S,U	Copper sulfate	81.9	72 hr	EC5 (cell numbers)	110	-	Bringmann 1978; Bringmann and Kuhn 1979, 1980a,
Protozoan, *Microrega heterostoma*	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, *Uronema parduezi*	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%	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, *Chlorella* 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, *Chlorella pyrenoidosa*	S,U	-	14.9	72 hr	IC50 (cell division rate)	24	-	Stauber and Florence 1989
Green alga, *Chlorella pyrenoidosa*	S,U	Copper sulfate	82	4 hr	Disturbed photosystem II	25	-	Vavilin et al. 1995
Green alga, *Eudorina californica*	S,U	Copper sulfate	19.1	-	Decrease in cell density	5,000	-	Young and Lisk 1972
Green alga (flagellate cells), *Haematococcus* 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

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Green alga, *Scenedesmus quadricauda*	S,U	Copper sulfate	34.8	24 hr	NOEC (growth)	50	-	Starodub et al. 1987
Green alga, *Scenedesmus quadricauda*	S,U	Copper sulfate	34.8	24 hr	NOEC (growth)	50	-	Starodub et al. 1987
Green alga, *Scenedesmus quadricauda*	S,U	Copper sulfate	34.8	24 hr	NOEC (growth)	>200	-	Starodub et al. 1987
Green alga, *Selenastrum capricornutum*	S,U	Copper chloride	14.9	7 days	Growth reduction	50	-	Bartlett et al.1974
Green alga, *Selenastrum capricornutum*	S,U	Copper sulfate	29.3	72 hr	EC50 (cell count)	19	-	Vasseur et al. 1988
Green alga, *Selenastrum capricornutum*	S,U	Copper sulfate	24.2	72 hr	EC50 (cell count)	41	-	Vasseur et al. 1988
Green alga, *Selenastrum capricornutum*	S,U	Copper sulfate	24.2	72 hr	EC50 (cell count)	28	-	Vasseur et al. 1988
Green alga, *Selenastrum capricornutum*	S,U	Copper sulfate	14.9	72 hr	EC50 (cell count)	60	-	Vasseur et al. 1988
Green alga, *Selenastrum capricornutum*	S,U	Copper sulfate	24.2	72 hr	EC50 (cell count)	28.5	-	Benhra et al. 1997
Green alga, *Selenastrum capricornutum*	F,U	Copper sulfate	15	24 hr	EC50 (cell density)	21	-	Chen et al. 1997
Diatom, *Cocconeis placentula*	Dosed stream	Copper sulfate	226-310	10 mo	Decreased abundance from 21% dowr to <1%	120	-	Weber and McFarland 1981
Phytoplankton, mixed species	S,U	-	-	124 hr	Averaged 39% reduction in primary production	10	-	Cote 1983
Macrophyte, *Elodea canadensis*	S,U	Copper sulfate	-	24 hr	EC50 (photosynthesis)	150	-	Brown and Rattigan 1979
Microcosm	F,M,T,D	Copper sulfate	200	32 wk	LOEC (primary production)	9.3	-	Hedtke 1984
Microcosm	F,M,T,D	Copper sulfate	200	32 wk	NOEC (primary production)	4	-	Hedtke 1984
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 sulfate	151	10 days	58% drop in no. of individuals	13.5	-	Clements et al. 1989
Microcosm	F,M,T	Copper sulfate	68	10 days	Significant drop in species richness and no. of individuals	11.3	-	Clements et al. 1990
Microcosm	F,M,T	Copper sulfate	80	10 days	Significant drop in species richness and no. of individuals	10.7	-	Clements et al. 1990
Microcosm	S,M,T	Copper sulfate	102	5 wk	14-28% drop in phytoplankton species richness	20	-	Winner and Owen 1991b
Microcosm	F,M,T	-	160	28 days	LOEC (species richness)	19.9	-	Pratt and Rosenberger 1993

Appendix B. Other Data on Effects of Copper on Freshwater Organisms

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	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, *Ephydatia fluviatilis*	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 (5^0 C)	1,300	-	Cairns et al. 1978
Rotifer, *Philodina acuticornis*	S,U	Copper sulfate	45	48 hr	LC50 (10^0 C)	1,200	-	Cairns et al. 1978
Rotifer, *Philodina acuticornis*	S,U	Copper sulfate	45	48 hr	LC50 (15^0 C)	1,130	-	Cairns et al. 1978
Rotifer, *Philodina acuticornis*	S,U	Copper sulfate	45	48 hr	LC50 (20^0 C)	1,000	-	Cairns et al. 1978
Rotifer, *Philodina acuticornis*	S,U	Copper sulfate	45	48 hr	LC50 (25^0 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), *Brachionus calyciflorus*	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), *Brachionus calyciflorus*	S, U	-	85	24 hr	EC50 (mobility)	26	-	Snell et al. 1991b

Appendix B. Other Data on Effects of Copper on Freshwater Organisms

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Rotifer (<2 hr), *Brachionus calyciflorus*	S, U	-	85	24 hr	EC50 (mobility; 10^0 C)	18	-	Snell 1991; Snell et al. 1991b
Rotifer (<2 hr), *Brachionus calyciflorus*	S, U	-	85	24 hr	EC50 (mobility; 15^0 C)	31	-	Snell 1991; Snell et al. 1991b
Rotifer (<2 hr), *Brachionus calyciflorus*	S, U	-	85	24 hr	EC50 (mobility; 20^0 C)	31	-	Snell 1991; Snell et al. 1991b
Rotifer (<2 hr), *Brachionus calyciflorus*	S, U	-	85	24 hr	EC50 (mobility; 25^0 C)	26	-	Snell 1991; Snell et al. 1991b
Rotifer (<2 hr), *Brachionus calyciflorus*	S, U	-	85	24 hr	EC50 (mobility; 30^0 C)	25	-	Snell 1991; Snell et al. 1991b
Rotifer (<3 hr), *Brachionus rubens*	S, U	Copper sulfate	90	24 hr	LC50	19	-	Snell and Persoone 1989b
Rotifer, *Keratella cochlearis*	S,U	Copper chloride	-	24 hr	LC50	101	-	Borgman and Ralph 1984
Worm, *Aeolosoma headleyi*	S,U	Copper sulfate	45	48 hr	LC50 (5^0 C)	2,600	-	Cairns et al. 1978
Worm, *Aeolosoma headleyi*	S,U	Copper sulfate	45	48 hr	LC50 (10^0 C)	2,300	-	Cairns et al. 1978
Worm, *Aeolosoma headleyi*	S,U	Copper sulfate	45	48 hr	LC50 (15^0 C)	2,000	-	Cairns et al. 1978
Worm, *Aeolosoma headleyi*	S,U	Copper sulfate	45	48 hr	LC50 (20^0 C)	1,650	-	Cairns et al. 1978
Worm, *Aeolosoma headleyi*	S,U	Copper sulfate	45	48 hr	LC50 (50 C)	1,000	-	Cairns et al. 1978
Worm (adult), *Lumbriculus variegatus*	S,U	Copper sulfate	30		LC50	150		Bailey and Liu, 1980
Worm (7 mg), *Lumbriculus variegatis*	F,M,T	Copper sulfate	45	10 days	LC50	35	-	West et al. 1993
Tubificid worm, *Limnodrilus hoffmeisteri*	S,U	Copper sulfate	100		LC50	102		Wurtz and Bridges 1961
Tubificid worm, *Tubifex tubifex*	R, U	Copper sulfate	245		LC50	158		Khangarot 1991
Snail (11-27 mm), *Campeloma decisum*	F,M,T	Copper sulfate	45	6 wk	LOEC (mortality)	14.8	-	Arthur and Leonard 1970
Snail, *Gyraulus circumstriatus*	S,U	Copper sulfate	100		LC50	108		Wurtz and Bridges 1961
Snail, *Goniobasis livescens*	S,U	Copper sulfate	154	48 hr	LC50	860	-	Cairns et al. 1976
Snail, *Goniobasis livescens*	S,M,D	Copper sulfate	154	96 hr	LC50	-	390	Paulson et al. 1983
Snail, *Nitrocris* sp.	S,U	Copper sulfate	45	48 hr	LC50 (5^0 C)	3,000	-	Cairns et al. 1978
Snail, *Nitrocris* sp.	S,U	Copper sulfate	45	48 hr	LC50 (10^0 C)	2,400	-	Cairns et al. 1978

Appendix B. Other Data on Effects of Copper on Freshwater Organisms

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Snail, *Nitrocris* sp.	S,U	Copper sulfate	45	48 hr	LC50 (15^0 C)	1,000	-	Cairns et al. 1978
Snail, *Nitrocris* sp.	S,U	Copper sulfate	45	48 hr	LC50 (20^0 C)	300	-	Cairns et al. 1978
Snail, *Nitrocris* sp.	S,U	Copper sulfate	45	48 hr	LC50 (25^0 C)	210	-	Cairns et al. 1978
Snail, *Lymnaea emarginata*	S,U	Copper sulfate	154	48 hr	LC50	300	-	Cairns et al. 1976
Snail (adult), *Juga plicifera*	F,M,T	Copper chloride	23	30 days	LC50	6	-	Nebeker et al. 1986b
Snail (adult), *Lithoglyphus virens*	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

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	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), *Medionidus conradicus*	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), *Medionidus conradicus*	R,M,T	Copper sulfate	170	48 hr		16		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Pygranodon grandis*	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), *Pygranodon grandis*	R,M,T	Copper sulfate	50	24 hr		46		Jacobson et al. 1997
Freshwater mussel (1-2 d), *Villosa iris*	S,M,T	Copper sulfate	190	24 hr	LC50	83	-	Jacobson et al. 1993
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	190	24 hr		80		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	190	24 hr		73		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	185	24 hr		65		Jacobson et al. 1997

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	185	24 hr		46		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	170	24 hr		75		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	160	24 hr		46		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	160	24 hr		36		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	155	24 hr		39		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	155	24 hr		37		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	150	24 hr		46		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	150	24 hr		46		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	55	24 hr		55		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	55	24 hr		38		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	50	24 hr		71		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	160	24 hr		46		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	170	48 hr		66		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	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

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Zebra mussel (1.6-2.0 cm), *Dreissena polymorpha*	R,M,T	Copper chloride	268	10 wk	NOEC (filtration rate)	13	-	Kraak et al. 1993
Asiatic clam (1.0-2.1 cm), *Coprbicula fluminea*	S,M,T	Copper 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

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	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), *Ceriodaphnia dubia*	S,M,D	-	113.6	48 hr	LC50	-	52	Belanger and Cherry 1990
Cladoceran (<12 hr), *Ceriodaphnia dubia*	S,M,D	-	113.6	48 hr	LC50	-	76	Belanger and Cherry 1990
Cladoceran (<12 hr), *Ceriodaphnia dubia*	S,M,D	-	113.6	48 hr	LC50	-	91	Belanger and Cherry 1990
Cladoceran (<48 h), *Ceriodaphnia dubia*	S,M,T	Copper nitrate	280 - 300	48 hr	LC50	9.5	-	Schubauer-Berigan et al. 1993
Cladoceran (<48 h), *Ceriodaphnia dubia*	S,M,T	Copper nitrate	280 - 300	48 hr	LC50	28	-	Schubauer-Berigan et al. 1993
Cladoceran (<48 h), *Ceriodaphnia dubia*	S,M,T	Copper nitrate	280 - 300	48 hr	LC50	200	-	Schubauer-Berigan et al. 1993
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S,M,T,D	Copper nitrate	100	48 hr	LC50	66	60.72	Spehar and Fiandt 1986
Cladoceran, *Ceriodaphnia dubia*	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, *Ceriodaphnia dubia*	R,U	Copper sulfate	90	-	LOEC (reproduction)	40	-	Zuiderveen and Birge 1997
Cladoceran, *Ceriodaphnia dubia*	R,M,T	-	20	-	IC50 (reproduction)	5	-	Jop et al. 1995
Cladoceran (<24 hrs), *Ceriodaphnia reticulata*	S, U	Copper chloride	240		EC50	23		Elnabarawy et al. 1986
Cladoceran, *Ceriodubia reticulata*	S,U	-	43-45		EC50	17		Mount and Norberg 1984
Cladoceran, *Daphnia magna*	-	Copper sulfate	-	72 hr	EC50 (mobility; 10^0 C)	61	-	Braginskij and Shcherben 1978

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cies	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Cladoceran, *Daphnia magna*	-	Copper sulfate	-	72 hr	EC50 (mobility; 15^0 C)	70	-	Braginskij and Shcherben 1978
Cladoceran, *Daphnia magna*	-	Copper sulfate	-	72 hr	EC50 (mobility; 20^0 C)	21	-	Braginskij and Shcherben 1978
Cladoceran, *Daphnia magna*	-	Copper sulfate	-	72 hr	EC50 (mobility; 30^0 C)	9.3	-	Braginskij and Shcherben 1978
Cladoceran, *Daphnia magna*	S,U	Copper sulfate	-	16 hr	EC 50 (mobility)	38	-	Anderson 1944
Cladoceran (<8 hr), *Daphnia magna*	S,U	Copper chloride	-	64 hr	Immobilization threshold	12.7	-	Anderson 1948
Cladoceran (1 mm), *Daphnia magna*	S,U	Copper nitrate	100	24 hr	EC 50 (mobility)	50	-	Bellavere and Gorbi 1981
Cladoceran (1 mm), *Daphnia magna*	S,U	Copper nitrate	200	24 hr	EC 50 (mobility)	70	-	Bellavere and Gorbi 1981
Cladoceran, *Daphnia magna*	S,U	-	100	48 hr	EC50 (mobility)	254	-	Borgmann and Ralph 1983
Cladoceran, *Daphnia magna*	S,U	-	100	49 hr	EC50 (mobility)	1,239	-	Borgmann and Ralph 1983
Cladoceran, *Daphnia magna*	S,U	Copper sulfate	45	48 hr	EC50 (mobility; 5^0 C)	90	-	Cairns et al. 1978
Cladoceran, *Daphnia magna*	S,U	Copper sulfate	45	48 hr	EC50 (mobility; 10^0 C)	70	-	Cairns et al. 1978
Cladoceran, *Daphnia magna*	S,U	Copper sulfate	45	48 hr	EC50 (mobility; 15^0 C)	40	-	Cairns et al. 1978
Cladoceran, *Daphnia magna*	S,U	Copper sulfate	45	48 hr	EC50 (mobility; 25^0 C)	7	-	Cairns et al. 1978
Cladoceran (4 days), *Daphnia magna*	S,U	Copper sulfate	-	24 hr	EC50 (filtration rate)	59	-	Ferrando and Andreu 1993
Cladoceran (24-48 hr), *Daphnia magna*	S,U	Copper sulfate	90	24 hr	EC50 (mobility)	380	-	Ferrando et al. 1992
Cladoceran, *Daphnia magna*	S,U	Copper sulfate	50		EC50	7		Oikari et al. 1992
Cladoceran, *Daphnia magna*	S,U	Copper sulfate	-	48 hr	EC50 (mobility)	45	-	Oikari et al. 1992
Cladoceran (<24 hr), *Daphnia magna*	S,U	Copper sulfate	145	Life span (ca. 18 wk)	Chronic limits (inst. rate of population growth)	70	-	Winner and Farrell 1976
Cladoceran (<24 hrs), *Daphnia magna*	S,M,D	Copper sulfate	72-80	48 hr	LC50	-	11.3	Suedel et al. 1996
Cladoceran (<24 hrs), *Daphnia magna*	S,M,I	-	180	-	LC50	55.3	-	Borgmann and Charlton 1984
Cladoceran (<24 hr), *Daphnia magna*	S,M,I	Copper sulfate	100	48 hr	EC50 (mobility)	46.0	-	Meador 1991
Cladoceran (<24 hr), *Daphnia magna*	S,M,I	Copper sulfate	100	48 hr	EC50 (mobility)	57.2	-	Meador 1991

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Cladoceran (<24 hr), *Daphnia magna*	S,M,I	Copper sulfate	100	48 hr	EC50 (mobility)	67.8	-	Meador 1991
Cladoceran (<24 hr), *Daphnia magna*	S,M,T	Copper sulfate	100	72 hr	EC50 (mobility)	52.8	-	Winner 1984b
Cladoceran (<24 hr), *Daphnia magna*	S,M,T	Copper sulfate	100	72 hr	EC50 (mobility)	56.3	-	Winner 1984b
Cladoceran (<24 hr), *Daphnia magna*	S,M,T	Copper chloride	85	96 hr	EC50 (mobility)	130	-	Blaylock et al. 1985
Cladoceran (24 hr), *Daphnia magna*	R,U	Copper sulfate	-	48 hr	EC50 (mobility)	18	-	Kazlauskiene et al. 1994
Cladoceran (<24 hr), *Daphnia parvula*	S,U	Copper sulfate	145	72 hr	EC50 (mobility)	72	-	Winner and Farrell 1976
Cladoceran (<24 hr), *Daphnia parvula*	S,U	Copper sulfate	145	72 hr	EC50 (mobility)	57	-	Winner and Farrell 1976
Cladoceran (<24 hr), *Daphnia parvula*	S,U	Copper sulfate	145	Life span (ca. 10 wk)	Chronic limits (inst. rate of population growth)	50	-	Winner and Farrell 1976
Cladoceran, *Daphnia pulex*	S,U	Copper sulfate	45		EC50	10		Cairns et al. 1978
Cladoceran, *Daphnia pulex*	S,U	-	45		EC50	53		Mount and Norberg 1984
Cladoceran (<24 hrs), *Daphnia pulex*	S, U	Copper chloride	240		EC50	31		Elnabarawy et al. 1986
Cladoceran (<24 hrs), *Daphnia pulex*	S, U	Copper sulfate	33.8		EC50	3.6		Koivisto et al. 1992
Cladoceran (<24 hrs), *Daphnia pulex*	S,U	Copper chloride	80-90		EC50	18		Roux et al. 1993
Cladoceran (<24 hrs), *Daphnia pulex*	S,U	Copper chloride	80-90		EC50	24		Roux et al. 1993
Cladoceran (<24 hrs), *Daphnia pulex*	S,U	Copper chloride	80-90		EC50	22		Roux et al. 1993
Cladoceran (<24 hr), *Daphnia pulex*	S,U	Copper sulfate	145	72 hr	EC50 (mobility)	86	-	Winner and Farrell 1976
Cladoceran (<24 hr), *Daphnia pulex*	S,U	Copper sulfate	145	72 hr	EC50 (mobility)	54	-	Winner and Farrell 1976
Cladoceran (<24 hr), *Daphnia pulex*	S,U	Copper sulfate	145	Life span (ca. 7 wk)	Chronic limits (inst. rate of population growth)	50	-	Winner and Farrell 1976
Cladoceran, *Daphnia pulex*	S,U	Copper sulfate	45	48 hr	EC50 (mobility)	70	-	Cairns et al. 1978
Cladoceran, *Daphnia pulex*	S,U	Copper sulfate	45	48 hr	EC50 (mobility)	60	-	Cairns et al. 1978
Cladoceran, *Daphnia pulex*	S,U	Copper sulfate	45	48 hr	EC50 (mobility)	20	-	Cairns et al. 1978
Cladoceran, *Daphnia pulex*	S,U	Copper sulfate	45	48 hr	EC50 (mobility)	56	-	Cairns et al. 1978

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Cladoceran (<24 hr), *Daphnia pulex*	S,U	Copper sulfate	200	24 hr	EC50 (mobility)	37.5	-	Lilius et al. 1995
Cladoceran, *Daphnia pulex*	S,M,T	Copper sulfate	106	48 hr	EC50 (mobility)	29	-	Ingersoll and Winner 1982
Cladoceran, *Daphnia pulex*	S,M,T	Copper sulfate	106	48 hr	EC50 (mobility)	20	-	Ingersoll and Winner 1982
Cladoceran, *Daphnia pulex*	S,M,T	Copper sulfate	106	48 hr	EC50 (mobility)	25	-	Ingersoll and Winner 1982
Cladoceran, *Daphnia pulex*	R,U	Copper sulfate	85	21 days	Reduced fecundity	3	-	Roux et al. 1993
Cladoceran, *Daphnia pulex*	R,M,T	Copper sulfate	106	70 days	Significantly shortened life span; reduced brood size	20	-	Ingersoll and Winner 1982
Cladoceran, *Daphnia pulicaria*	S,M,T	-	31	48 hr	EC50 (mobility; TOC=14 mg/L)	55.4	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	29	49 hr	EC50 (mobility; TOC=13 mg/L)	55.3	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	28	50 hr	EC50 (mobility; TOC=13 mg/L)	53.3	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	28	50 hr	EC50 (mobility; TOC=28 mg/L)	97.2	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	100	51 hr	EC50 (mobility; TOC=34 mg/L)	199	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	86	52 hr	EC50 (mobility; TOC=34 mg/L)	627	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	84	53 hr	EC50 (mobility; TOC=32 mg/L)	165	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	16	54 hr	EC50 (mobility; TOC=12 mg/L)	35.5	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	151	55 hr	EC50 (mobility; TOC=13 mg/L)	78.8	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	96	56 hr	EC50 (mobility; TOC=28 mg/L)	113	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	26	57 hr	EC50 (mobility; TOC=25 mg/L)	76.4	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	84	58 hr	EC50 (mobility; TOC=13 mg/L)	84.7	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	92	59 hr	EC50 (mobility; TOC=21 mg/L)	184	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	106	60 hr	EC50 (mobility; TOC=34 mg/L)	240	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	Copper sulfate	106	48 hr	LC50	240	-	Lind et al. manuscript
Cladoceran, *Simocephalus serrulatus*	S,M,T	Copper nitrate	8	24 hr	EC50 (mobility; TOC=11 mg/L)	12	-	Giesy et al. 1983

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Cladoceran, *Simocephalus serrulatus*	S,M,T	Copper nitrate	16	25 hr	EC50 (mobility; TOC=12.4 mg/L)	7.2	-	Giesy et al. 1983
Cladoceran, *Simocephalus serrulatus*	S,M,T	Copper nitrate	16	26 hr	EC50 (mobility; TOC=15.6 mg/L)	24.5	-	Giesy et al. 1983
Cladoceran (<24 hr), *Simocephalus vetulus*	S,U	-	45			57		Mount and Norberg 1984
Cladoceran (life cycle), *Bosmina longirostris*	R,U	Copper sulfate	-	13 days	LOEC (intrinsic rate of population increase)	18	-	Koivisto and Ketola 1995
Copepods (mixed sp), Primarily *Acanthocyclops vernalis* and *Diacyclops thomasi*	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), *Crangonyx pseudogracilis*	R,U	Copper sulfate	45-55			1290		Martin and Holdich 1986
Amphipod (4 mm), *Crangonyx psuedogracilis*	R,U	Copper sulfate	50	48 hr	LC50	2,440	-	Martin and Holdich 1986
Amphipod, *Gammarus fasciatus*	S,U	Copper sulfate	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), *Hyallela azteca*	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), *Cambarus robustus*	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

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	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), *Orconectes* 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), *Stenonema* sp.	S,M,T	-	110	48 hr	LC50	453	-	Dobbs et al. 1994
Mayfly, *Cloeon dipterium*	-	Copper sulfate	-	72 hr	LC50 (10^0 C)	193	-	Braginskij and Shcherban 1978
Mayfly, *Cloeon dipterium*	-	-	-	72 hr	LC50 (15^0 C)	95.2	-	Braginskij and Shcherban 1978
Mayfly, *Cloeon dipterium*	-	-	-	72 hr	LC50 (25^0 C)	53	-	Braginskij and Shcherban 1978
Mayfly, *Cloeon dipterium*	-	-	-	72 hr	LC50 (30^0 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, *Hydropsyche betteni*	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), *Chironomus tentans*	S,U	Copper sulfate	42.7			16.7		Gauss et al. 1985
Midge (1st instar), *Chironomus tentans*	S,U	Copper sulfate	109.6			36.5		Gauss et al. 1985
Midge (1st instar), *Chironomus tentans*	S,U	Copper sulfate	172.3			98.2		Gauss et al. 1985
Midge (4th instar), *Chironomus tentans*	S,U	Copper sulfate	42.7			211		Gauss et al. 1985
Midge (4th instar), *Chironomus tentans*	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

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	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), *Plumatella emarginata*	S,U	-	190-220			140		Pardue and Wood 1980
American eel (5.5 cm glass eel stage), *Anguilla rostrata*	S,U	Copper sulfate	40-48	96 hr	LC50	2,540		Hinton and Eversole 1978
American eel (9.7 cm black eel stage), *Anguilla rostrata*	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), *Thymallus arcticus*	S,U	Copper sulfate	41.3	96 hr	LC50	2.7		Buhl and Hamilton 1990
Arctic grayling (0.34 g juvenile), *Thymallus arcticus*	S,U	Copper sulfate	41.3	96 hr	LC50	2.58		Buhl and Hamilton 1990
Arctic grayling (0.81 g juvenile), *Thymallus arcticus*	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

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	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), *Oncorhynchus kisutch*	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

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	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), *Oncorhynchus nerka*	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), *Oncorhynchus nerka*	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	-	Finlayson 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

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	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 (5^0 C)	950	-	Cairns et al. 1978
Rainbow trout (4.0-10.6 cm), *Oncorhynchus mykiss*	S,U	Copper sulfate	45	24 hr	LC50 (15^0 C)	430	-	Cairns et al. 1978
Rainbow trout (4.0-10.6 cm), *Oncorhynchus mykiss*	S,U	Copper sulfate	45	24 hr	LC50 (30^0 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

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	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) *Oncorhynchus mykiss*	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

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	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), *Oncorhynchus mykiss*	F,M,T	Copper chloride	24	200 hr	LC50	20	-	Chapman 1978
Rainbow trout (alevin), *Oncorhynchus mykiss*	F,M,T	Copper chloride	24	200 hr	LC10	19	-	Chapman 1978
Rainbow trout (swimup), *Oncorhynchus mykiss*	F,M,T	Copper chloride	24	200 hr	LC50	17	-	Chapman 1978
Rainbow trout (swimup), *Oncorhynchus mykiss*	F,M,T	Copper chloride	24	200 hr	LC10	9	-	Chapman 1978
Rainbow trout (parr), *Oncorhynchus mykiss*	F,M,T	Copper chloride	25	200 hr	LC50	15	-	Chapman 1978
Rainbow trout (parr), *Oncorhynchus mykiss*	F,M,T	Copper chloride	25	200 hr	LC10	8	-	Chapman 1978
Rainbow trout (smolt), *Oncorhynchus mykiss*	F,M,T	Copper chloride	25	200 hr	LC50	21	-	Chapman 1978
Rainbow trout (smolt), *Oncorhynchus mykiss*	F,M,T	Copper chloride	25	200 hr	LC10	7	-	Chapman 1978
Rainbow trout, *Oncorhynchus mykiss*	F,M,T	Copper sulfate	112.4	80 min	Avoidance threshold	74	-	Black and Birge 1980
Rainbow trout (>8 g), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	49	15-18 days	LC50	48	-	Miller and MacKay 1980
Rainbow trout (>8 g), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	51	15-18 days	LC50	46	-	Miller and MacKay 1980
Rainbow trout (>8 g), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	57	15-18 days	LC50	63	-	Miller and MacKay 1980
Rainbow trout (>8 g), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	12	15-18 days	LC50	19	-	Miller and MacKay 1980
Rainbow trout (>8 g), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	99	15-18 days	LC50	54	-	Miller and MacKay 1980
Rainbow trout (>8 g), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	98	15-18 days	LC50	78	-	Miller and MacKay 1980
Rainbow trout (>8 g), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	12	15-18 days	LC50	18	-	Miller and MacKay 1980
Rainbow trout (>8 g), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	97	15-18 days	LC50	96	-	Miller and MacKay 1980
Rainbow trout (200-250 g), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	320	4 mo	Altered liver and blood enzymes and mitochondrial function	30	-	Arillo et al. 1984
Rainbow trout (7 cm), *Oncorhynchus mykiss*	F,M,T	Copper chloride	28.4	20 min	Avoidance	6.4	-	Giattina et al. 1982
Rainbow trout (2.70 g), *Oncorhynchus mykiss*	F,M,T	Copper chloride	9.2	96 hr	LC50	4.2	-	Cusimano et al. 1986
Rainbow trout (2.88 g), *Oncorhynchus mykiss*	F,M,T	Copper chloride	9.2	96 hr	LC50	66	-	Cusimano et al. 1986

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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), *Oncorhynchus mykiss*	F,M,T	Copper chloride	9.2	168 hr	LC50	3.1	-	Cusimano et al. 1986
Rainbow trout (2.65 g), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	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), *Oncorhynchus mykiss*	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

Appendix B. Other Data on Effects of Copper on Freshwater Organisms

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Rainbow trout (12.3 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	362	144 hr	LC50 (Low carbohydrate diet)	408	-	Dixon and Hilton 1981
Rainbow trout (11.6 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	362	144 hr	LC50 (high carbohydrate diet)	246	-	Dixon and Hilton 1981
Rainbow trout (1.7-3.3 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	374	21 days	Incipient lethal level	329	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	374	21 days	Incipient lethal level	333	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	374	21 days	Incipient lethal level	311	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	374	21 days	Incipient lethal level	274	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	374	21 days	Incipient lethal level	371	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	374	21 days	Incipient lethal level (acclimated to 30 ug/L)	266	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	374	21 days	Incipient lethal level (acclimated to 58 ug/L)	349	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	374	21 days	Incipient lethal level (acclimated to 94 ug/L)	515	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	374	21 days	Incipient lethal level (acclimated to 13 ug/L)	564	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	374	21 days	Incipient lethal level (acclimated to 19 ug/L)	708	-	Dixon and Sprague 1981a
Rainbow trout (2.9 g), *Oncorhynchus mykiss*	F,M,D	Copper chloride	30.5	ca. 2 hr	Inhibited avoidance of serine	6.667	-	Rehnberg and Schreck 1986
Rainbow trout (3.2 g), *Oncorhynchus mykiss*	F,M,T,D	Copper sulfate	30	96 hr	LC50	-	19.9	Howarth and Sprague 1978
Rainbow trout (1.4 g), *Oncorhynchus mykiss*	F,M,T,D	Copper sulfate	101	96 hr	LC50	-	176	Howarth and Sprague 1978
Rainbow trout (2.2 g), *Oncorhynchus mykiss*	F,M,T,D	Copper sulfate	370	96 hr	LC50	-	232	Howarth and Sprague 1978
Rainbow trout (smolt), *Oncorhynchus mykiss*	F,M,T,D	Copper sulfate	363	>10 days	LC50	97.92	-	Fogels and Sprague 1977
Rainbow trout (parr), *Oncorhynchus mykiss*	F,M,T,D,I	-	31.0	62 days	NOEC (growth and survival)	90	-	Mudge et al. 1993
Atlantic salmon (2-3 yr parr), *Salmo salar*	S,M,T	-	8-10	96 hr	LC50	125	-	Wilson 1972
Atlantic salmon (6.4-11.7 cm), *Salmo salar*	F,M,T	Copper sulfate	20	7 days	LC50	48	-	Sprague 1964
Atlantic salmon (7.2-10.9 cm), *Salmo salar*	F,M,T	-	14	7 days	LC50	32	-	Sprague and Ramsay 1965
Brown trout (3-6 day larva), *Salmo trutta*	S,M,T	Copper chloride	4	30 days	>90% mortality	80	-	Reader et al. 1989

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	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), *Salvelinus fontinalis*	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), *Carassius auratus*	S,U	Copper sulfate	20	96 hr	LC50	36		Pickering and Henderson 1966
Goldfish (10.5 g), *Carassius auratus*	S,M,T	Copper sulfate	34.2	-	LC50	150	-	Hossain et al. 1995
Goldfish (embryo), *Carrassius auratus*	R,U	Copper sulfate	195	7 days	EC50 (death or deformity)	5,200	-	Birge 1978; Birge and Black 1979
Goldfish, *Carassius auratus*	R,U	Copper sulfate	45	24 hr	LC50 (5^0 C)	2,700	-	Cairns et al. 1978
Goldfish, *Carassius auratus*	R,U	Copper sulfate	45	24 hr	LC50 (15^0 C)	2,900	-	Cairns et al. 1978
Goldfish, *Carassius auratus*	R,U	Copper sulfate	45	24 hr	LC50 (30^0 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), *Cyprinus carpio*	S,U	Copper sulfate	360	-	EC50 (hatch and deformity)	4,775	-	Kapur and Yadav 1982
Common carp (embryo), *Cyprinus carpio*	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), *Cyprinus carpio*	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

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	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), *Gila elegans*	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 (5^0 C)	330	-	Cairns et al. 1978
Golden shiner, *Notemigonus crysoleucas*	S,U	Copper sulfate	45	24 hr	LC50 (15^0 C)	230	-	Cairns et al. 1978
Golden shiner, *Notemigonus crysoleucas*	S,U	Copper sulfate	45	24 hr	LC50 (30^0 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

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	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, *Pimephales notatus*	S,U	Copper sulfate	208	48 hr	LC50	290	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,U	Copper sulfate	132	48 hr	LC50	150	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,U	Copper sulfate	182	48 hr	LC50	200	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,U	Copper sulfate	233	48 hr	LC50	180	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,U	Copper sulfate	282	48 hr	LC50	260	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,U	Copper sulfate	337	48 hr	LC50	260	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,U	Copper sulfate	322	48 hr	LC50	6,300	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,U	Copper sulfate	322	48 hr	LC50	11,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,U	Copper sulfate	322	48 hr	LC50	25,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,U	Copper sulfate	203	48 hr	LC50	160	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,U	Copper sulfate	203	48 hr	LC50	1,100	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,U	Copper sulfate	203	48 hr	LC50	2,900	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	320	48 hr	LC50	6,300	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	324	48 hr	LC50	9,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	324	48 hr	LC50	4,700	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	320	48 hr	LC50	11,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	318	48 hr	LC50	5,700	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	318	48 hr	LC50	10,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	314	48 hr	LC50	8,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	318	48 hr	LC50	11,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	324	48 hr	LC50	9,700	-	Geckler et al. 1976

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	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, *Pimephales notatus*	S,M,D	Copper sulfate	310	48 hr	LC50	12,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	310	48 hr	LC50	21,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	302	48 hr	LC50	19,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	296	48 hr	LC50	8,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	332	48 hr	LC50	11,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	340	48 hr	LC50	6,300	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	296	48 hr	LC50	1,500	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	306	48 hr	LC50	750	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	308	48 hr	LC50	2,500	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	304	48 hr	LC50	1,600	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	315	48 hr	LC50	4,000	-	Geckler et al. 1976
Bluntnose minnow (3.9 cm), *Pimephales notatus*	F,M,T,D	Copper sulfate	314	96 hr	LC50	6,800	-	Geckler et al. 1976
Bluntnose minnow (5.3 cm), *Pimephales notatus*	F,M,T,D	Copper sulfate	303	96 hr	LC50	13,000	-	Geckler et al. 1976
Fathead minnow (adult), *Pimephales promelas*	S,U	Copper sulfate	103-104	96 hr	LC50	210		Birge et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S,U	Copper sulfate	103-104	96 hr	LC50	310		Birge et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S,U	Copper sulfate	103-104	96 hr	LC50	120		Birge et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S,U	Copper sulfate	103-104	96 hr	LC50	210		Birge et al. 1983; Benson and Birge 1985
Fathead minnow (adult), *Pimephales promelas*	S,U	Copper sulfate	254-271	96 hr	LC50	390		Birge et al. 1983; Benson and Birge 1985
Fathead minnow, *Pimephales promelas*	S,U	Copper sulfate	200	96 hr	LC50	430		Mount 1968
Fathead minnow, *Pimephales promelas*	S,U	Copper sulfate	31	96 hr	LC50	84		Mount and Stephan 1969
Fathead minnow (3.8-6.3 cm), *Pimephales promelas*	S,U	Copper sulfate	20	96 hr	LC50	25		Pickering and Henderson 1966

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	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), *Pimephales promelas*	S,M	Copper acetate	44	96 hr	LC50	117	-	Curtis et al. 1979; Curtis and Ward 1981
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	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), *Pimephales promelas*	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

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	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), *Pimephales promelas*	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), *Pimephales promelas*	S,M,T	Copper sulfate	19.0	96 hr	LC50	70.3	-	Welsh et al. 1993
Fathead minnow (<24 h), *Pimephales promelas*	S,M,T	Copper sulfate	19.0	96 hr	LC50	85.6	-	Welsh et al. 1993
Fathead minnow (<24 h), *Pimephales promelas*	S,M,T	Copper sulfate	19.0	96 hr	LC50	182.0	-	Welsh et al. 1993
Fathead minnow (<24 h; 0.68 mg), *Pimephales promelas*	S,M,T	Copper sulfate	17	96 hr	LC50	1.99	-	Welsh et al. 1993

Appendix B. Other Data on Effects of Copper on Freshwater Organisms

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Fathead minnow (<24 h; 0.68 mg), *Pimephales promelas*	S,M,T	Copper sulfate	20.5	96 hr	LC50	4.86	-	Welsh et al. 1993
Fathead minnow (<24 h; 0.68 mg), *Pimephales promelas*	S,M,T	Copper sulfate	16.5	96 hr	LC50	11.1	-	Welsh et al. 1993
Fathead minnow (<24 h; 0.68 mg), *Pimephales promelas*	S,M,T	Copper sulfate	17.5	96 hr	LC50	9.87	-	Welsh et al. 1993
Fathead minnow (<24 h; 0.68 mg), *Pimephales promelas*	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), *Pimephales promelas*	S,M,T	Copper sulfate	9.9	96 hr	LC50	10.7	-	Welsh et al. 1996
Fathead minnow (<24 hrs), *Pimephales promelas*	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), *Pimephales promelas*	S,M,T	Copper sulfate	16.8	96 hr	LC50	26.8	-	Welsh et al. 1996
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T	Copper sulfate	12.2	96 hr	LC50	21.2	-	Welsh et al. 1996
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T	Copper sulfate	9.4	96 hr	LC50	19.8	-	Welsh et al. 1996
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T	Copper sulfate	11.4	96 hr	LC50	31.9	-	Welsh et al. 1996
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T	Copper sulfate	10.9	96 hr	LC50	26.1	-	Welsh et al. 1996
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T	Copper sulfate	12.4	96 hr	LC50	26.0	-	Welsh et al. 1996
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T	Copper sulfate	17.4	96 hr	LC50	169.5	-	Welsh et al. 1996
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T,D	Copper sulfate	46	96 hr	LC50	17.15	14.87	Erickson et al. 1996a,b
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T,D	Copper sulfate	46	96 hr	LC50	21.59	18.72	Erickson et al. 1996a,b

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	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), *Pimephales promelas*	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), *Pimephales promelas*	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

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	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), *Pimephales promelas*	R,M,T,D	Copper sulfate	80	48 hr	LC50	297.1	-	Diamond et al. 1997b
Fathead minnow (3-7 days), *Pimephales promelas*	R,M,T,D	Copper sulfate	72	48 hr	LC50	145.8	-	Diamond et al. 1997b
Fathead minnow (32-38 mm), *Pimephales promelas*	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), *Pimephales promelas*	F,M,T	Copper sulfate	10.7	21 days	Growth (length) reduced by 8%	5.3	-	Welsh 1996
Fathead minnow (24-96 hr), *Pimephales promelas*	F,M,T	Copper sulfate	9.3	21 days	Incipient lethal level	17.2	-	Welsh 1996
Fathead minnow (24-96 hr), *Pimephales promelas*	F,M,T	Copper sulfate	9.3	21 days	Growth (length) reduced by 17%	16.2	-	Welsh 1996
Fathead minnow (<24 hrs), *Pimephales promelas*	F,M,T	Copper sulfate	46	96 hr	LC50	305	-	Erickson et al. 1996 a,b
Fathead minnow (<24 hrs), *Pimephales promelas*	F,M,T	Copper sulfate	46	96 hr	LC50	298.6	-	Erickson et al. 1996 a, b
Fathead minnow, *Pimephales promelas*	F,M,T	-	30	96 hr	LC50 (TOC=12 mg/L)	436	-	Lind et al. manuscript
Fathead minnow, *Pimephales promelas*	F,M,T	-	37	96 hr	LC50 (TOC=13 mg/L)	516	-	Lind et al. manuscript
Fathead minnow, *Pimephales promelas*	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, *Pimephales promelas*	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

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Fathead minnow, *Pimephales promelas*	F,M,T	-	117	96 hr	LC50 (TOC=30 mg/L)	2,050	-	Lind et al. manuscript
Fathead minnow, *Pimephales promelas*	F,M,T	-	121	96 hr	LC50 (TOC=30 mg/L)	2,336	-	Lind et al. manuscript
Fathead minnow, *Pimephales promelas*	F,M,T	Copper sulfate	117	96 hr	LC50	2,050	-	Lind et al. manuscript
Fathead minnow, *Pimephales promelas*	F,M,T	Copper sulfate	121	96 hr	LC50	2,336	-	Lind et al. manuscript
Fathead minnow (4.4 cm), *Pimephales promelas*	F,M,T,D	Copper sulfate	314	96 hr	LC50	11,000	-	Geckler et al. 1976
Fathead minnow (4.2 cm), *Pimephales promelas*	F,M,T,D	Copper sulfate	303	96 hr	LC50	15,000	-	Geckler et al. 1976
Fathead minnow (<24 hrs), *Pimephales promelas*	F,M,T,D	Copper sulfate	45	96 hr	LC50	158.8	138.1	Erickson et al. 1996a,b
Fathead minnow (<24 hrs), *Pimephales promelas*	F,M,T,D	Copper sulfate	45	96 hr	LC50	80.01	72.01	Erickson et al. 1996a,b
Fathead minnow (<24 hrs), *Pimephales promelas*	F,M,T,D	Copper sulfate	46	96 hr	LC50	20.96	18.23	Erickson et al. 1996a,b
Fathead minnow (<24 hrs), *Pimephales promelas*	F,M,T,D	Copper sulfate	44	96 hr	LC50	50.8	39.12	Erickson et al. 1996a,b
Fathead minnow (<24 hrs), *Pimephales promelas*	F,M,T,D	Copper sulfate	45	96 hr	LC50	65.41	45.78	Erickson et al. 1996a,b
Colorado squawfish (larva), *Ptychocheilus lucius*	S,U	Copper sulfate	199	96 hr	LC50	363		Buhl and Hamilton 1996
Colorado squawfish (155-186 days), *Ptychocheilus lucius*	S,U	Copper sulfate	199	96 hr	LC50	663		Buhl and Hamilton 1996
Colorado squawfish (32-40 days posthatch), *Ptychocheilus lucius*	S,U	Copper sulfate	144	96 hr	LC50	293		Hamilton and Buhl 1997
Colorado squawfish (32-40 days posthatch), *Ptychocheilus lucius*	S,U	Copper sulfate	144	96 hr	LC50	320		Hamilton and Buhl 1997
Creek chub, *Semotilus atromaculatus*	F,M,T	Copper sulfate	316	96 hr	LC50	11,500	-	Geckler et al. 1976
Creek chub, *Semotilus atromaculatus*	F,M,T	Copper sulfate	274	96 hr	LC50	1,100	-	Geckler et al. 1976
Razorback sucker (larva), *Xyrauchen texanus*	S,U	Copper sulfate	199	96 hr	LC50	404		Buhl and Hamilton 1996
Razorback sucker (102-116 days), *Xyrauchen texanus*	S,U	Copper sulfate	199	96 hr	LC50	331		Buhl and Hamilton 1996
Razorback sucker (13-23 days posthatch), *Xyrauchen texanus*	S,U	Copper sulfate	144	96 hr	LC50	231		Hamilton and Buhl 1997

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Razorback sucker (13-23 days posthatch), *Xyrauchen texanus*	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 (5^0 C)	3,700	-	Cairns et al. 1978
Channel catfish, *Ictalurus punctatus*	S,U	Copper sulfate	45	24 hr	LC50 (15^0 C)	2,600	-	Cairns et al. 1978
Channel catfish, *Ictalurus punctatus*	S,U	Copper sulfate	45	24 hr	LC50 (30^0 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,T	Copper sulfate	-	10 wk	Significant mortality	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 catfish (5.7 gm), *Ictalurus punctatus*	F,M,T,D	Copper sulfate	315	14 days	LC50	1,073	-	Richey and Roseboom 1978
Banded killifish, *Fundulus diaphanus*	S,M,T	Copper nitrate	53	-		860	-	Rehwoldt et al. 1971
Banded killifish, *Fundulus diaphanus*	S,M,T	Copper nitrate	55	-		840	-	Rehwoldt et al. 1972

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	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), *Gambusia affinis*	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), *Gambusia affinis*	S,U	-	300	96 hr	LC50	2,000		Kallanagoudar and Patil 1997
Mosquito fish, *Gambusia affinis*	S,U	Copper sulfate	-	96 hr	LC50 (high turbidity)	75,000	-	Wallen et al. 1957
Mosquito fish, *Gambusia affinis*	R,M	Copper sulfate	45	48 hr	LC50	180	-	Chagnon and Guttman 1989
Guppy (1.5 cm), *Poecilia reticulata*	S,U	Copper sulfate	230	96 hr	LC50	1,230		Khangarot 1981
Guppy (1.62 cm), *Poecilia reticulata*	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

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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), *Poecilia reticulata*	F,U	Copper sulfate	76	24 hr	LC50	930	-	Minicucci 1971
Guppy (1 mo), *Poecilia reticulata*	F,U	Copper sulfate	76	24 hr	LC50	1,130	-	Minicucci 1971
White perch, *Morone americana*	S,M,T	Copper nitrate	53	-	LC50	6,200	-	Rehwoldt et al. 1971
White perch, *Morone americana*	S,M,T	Copper nitrate	55	-	LC50	6,400	-	Rehwoldt et al. 1972
Striped bass (larva), *Morone saxitilis*	S,U	Copper chloride	34.6	96 hr	LC50	50		Hughes 1973
Striped bass (larva), *Morone saxitilis*	S,U	Copper sulfate	34.6	96 hr	LC50	100		Hughes 1973
Striped bass (3.5-5.1 cm), *Morone saxitilis*	S,U	Copper chloride	34.6	96 hr	LC50	50		Hughes 1973
Striped bass (3.1-5.1 cm), *Morone saxitilis*	S,U	Copper sulfate	34.6	96 hr	LC50	150		Hughes 1973
Striped bass (35-80 day), *Morone saxitilis*	S,U	Copper sulfate	285	96 hr	LC50	270		Palawski et al. 1985
Striped bass (6 cm), *Morone saxitilis*	S,U	Copper sulfate	35	96 hr	LC50	620		Wellborn 1969
Striped bass, *Morone saxitilis*	S,M,T	Copper nitrate	53	96 hr	LC50	4,300	-	Rehwoldt et al. 1971
Striped bass, *Morone saxitilis*	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, *Lepomis gibbosus*	S,M,T	Copper nitrate	53	96 hr	LC50	2,400	-	Rehwoldt et al. 1971
Pumpkinseed, *Lepomis gibbosus*	S,M,T	Copper nitrate	55	96 hr	LC50	2,700	-	Rehwoldt et al. 1972

Appendix B. Other Data on Effects of Copper on Freshwater Organisms

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (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 et
Bluegill, *Lepomis macrochirus*	S,U	Copper sulfate	45	24 hr	LC50 (5^0 C)	2,590	-	Cairns et al. 1978
Bluegill, *Lepomis macrochirus*	S,U	Copper sulfate	45	24 hr	LC50 (15^0 C)	2,500	-	Cairns et al. 1978
Bluegill, *Lepomis macrochirus*	S,U	Copper sulfate	45	24 hr	LC50 (30^0 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), *Lepomis macrochirus*	S,U	Copper sulfate	209	96 hr	LC50	437		Inglis and Davis 1972
Bluegill (4.2 cm), *Lepomis macrochirus*	S,U	Copper sulfate	365	96 hr	LC50	648		Inglis and Davis 1972
Bluegill (5-15 g), *Lepomis macrochirus*	S,U	Copper sulfate	35	2-6 days	8% increase in oxygen consumption rates	300	-	O'Hara 1971
Bluegill (3.8-6.3 cm), *Lepomis macrochirus*	S,U	Copper sulfate	20	96 hr	LC50	660		Pickering and Henderson 1966
Bluegill (3.8-6.3 cm), *Lepomis macrochirus*	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), *Lepomis macrochirus*	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

Appendix B. Other Data on Effects of Copper on Freshwater Organisms

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	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), *Micropterus salmoides*	R,U	Copper sulfate	100	8 days	EC50 (death and deformity)	6,560	-	Birge et al. 1978; Birge and Black 1979
Largemouth bass, *Micropterus salmoides*	F,U	-	-	24 hr	Affected opercular rhythm	48	-	Morgan 1979
Rainbow darter, *Etheostoma caeruleum*	F,M,T,D	Copper sulfate	318	96 hr	LC50 (high BOD)	4,500	-	Geckler et al. 1976
Rainbow darter, *Etheostoma caeruleum*	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_4) 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.

Table 1. Standard Reconstituted Water Composition and Target Water Quality Characteristics

	Reagent Added (mg/L)				Final Water Quality		
Water Type	$NaHCO_3$	$CaSO_4 \bullet 2H_2O$	$MgSO_4$	KCl	pH[a]	Hardness[a]	Alkalinity[b]
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

[a] Approximate equilibrium pH after 24-hour aeration
[b] Expressed as mg/L $CaCO_3$

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 $CaCO_3$, 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 $CaCO_3$, 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:

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

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

The remaining ion concentrations are each multiplied by 0.92 (quotient of 78 and 85 mg/L $CaCO_3$, 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

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

Water Type (Nominal Hardness Range)	Specific Ions[a] (mg/L)							
	Ca	Mg	Na	K	Cl	SO_4	Ca:Mg[b]	Expected Hardness (mg/L $CaCO_3$)[c]
Very Soft (10-13 mg/L $CaCO_3$)	1.75	1.51	3.28	0.262	0.238	10.2	0.700	11
Soft (40-48 mg/L $CaCO_3$)	6.99	6.06	13.1	1.05	0.951	40.7	0.700	42
Moderately Hard (80-100 mg/L $CaCO_3$)	14.0	12.1	26.3	2.10	1.90	81.4	0.700	85
Hard (160-180 mg/L $CaCO_3$)	27.9	24.2	52.5	4.20	3.80	163	0.700	170
Very Hard (280-320 mg/L $CaCO_3$)	55.9	48.5	105	8.39	7.61	325	0.700	339

[a] Ion concentrations were calculated from standard salt recipes (refer to Table 1 and example calculation for very soft water in Appendix D-1).
[b] 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.
[c] 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

Moderately Hard Reconstituted Water	Hardness (mg/L $CaCO_3$)	Specific Ions (mg/L)					
		Ca	Mg	Na	K	Cl	SO_4
Nominal	85[a]	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***

[a] 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 $CaCO_3$ is: 78÷85=0.92; 0.92*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 from values reported for TOC.

<u>*Example*</u>:

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 mg/L (1.27 mg/L × 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_4 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.

Table 4. Recommended Spreadsheet Addition for Lake Superior Dilution Water

Applied to:	Hardness (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)	Specific Ions (mg/L) Ca	Mg	Ca:Mg	Na	K	Cl	SO_4
Pre-1987[a]	46	42	13.6	3.0	2.75	1.3	0.57	1.2	3.4
Post-1987[b]	46	43	13.6	2.9	2.84	1.5	0.59	1.2	3.4

[a] Mean of the Erickson et al. (1996b) and Biesinger and Christensen (1972) water chemistry data

[b] 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 $CaCO_3$. Over the remaining months (particularly from July to November), hardness stabilizes at around 25 to 40 mg/L $CaCO_3$, 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 $CaCO_3$) 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^2) 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:

[Ca] = 0.3085 + (measured hardness * 0.2738)
[Mg] = 0.5429 + (measured hardness * 0.0573)
[Na] = 3.3029 + (measured hardness * 0.0713)
[Cl] = 2.7842 + (measured hardness * 0.1278)
[SO_4] = -3.043 + (measured hardness * 0.2816)

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 (Mean Measured value) mg/L $CaCO_3$	Predicted Ion Concentrations (mg/L)					
	Ca	Mg	Na	Cl	SO_4	Default[a] 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

[a] Value not corrected. Assume default value of 0.70 mg/L.

Recommended Spreadsheet Addition for Oregon Well Water.

Applied to:	Hardness (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)	pH	DOC	Specific Ions[a] (mg/L)						
					Ca	Mg	Ca:Mg	Na	K	Cl	SO_4
Lorz and McPherson 1976	95	66	6.8-7.9	1.6[B]	19	12	1.0	7.6	1.0	7.0	12
Seim et al. 1984	120	126	7.7	1.6[B]	34	8.6	2.4	15	0.7	5.0	2.3

[a] 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).
[b] 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_3), 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 acid-soluble 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_3 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.

Table 6. Comparison of Values for Untreated (Natural) and Treated (Dechlorinated City of Blacksburg, VA) New River Water

Source	Water Type	pH	Total Hardness (mg/L $CaCO_3$)	Total Alkalinity (mg/L $CaCO_3$)	Specific Ions (mg/L)							Ca:Mg ratio	DOC (mg/L)
					Ca	Mg	Na	K	Cl	SO_4	NO_3		
Acquired Data													
City of Blacksburg, VA[a]	City	8.5	44	39	-	-	9.3	-	33	45	-	-	1.5
Cherry 2000 (08/00)[b]	New R.	8.0	-	52	15	0.6	6.6	2.0	6.1	9.8	0.7		2
NASQAN[c]	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 Tests[d]													
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

[a] 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.

[b] 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.

[c] 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.

[d] 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.

Table 7. Estimated Alkalinity in Natural Surface Water Based on pH

Source Water	Nominal pH	Alkalinity (mg/L $CaCO_3$)
New River	6	24.5
	8.1	74.2[a]
	9	77.9
Clinch River	6	47.6
	8.3	144[a]
	9	152
Amy Bayou	6	40.2
	8.3	122[a]
	9	128

[a] 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 Organic Carbon and Percent Humic Acid for the Winner (1985) Toxicity Tests

Humic Acid Added (mg/L)[a]	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

[a] 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 $CaCO_3$ (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 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 × 35.453 mg Cl/1 mmol Cl
= 12.12 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 spreadsheet addition for Chehalis River dilution water

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

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

[a] 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 $CaCO_3$ at pH 9, one obtains an estimated alkalinity value of 341 mg/L $CaCO_3$. In contrast, the measured alkalinity reported in the text for this level of hardness and pH was 263 mg/L $CaCO_3$.

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 $CaCO_3$ and a pH of 7.75, the alkalinity calculated with the equation is 98 mg/L $CaCO_3$. This compares rather poorly with the measured alkalinity of 223 mg/L $CaCO_3$. 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 de-ionized 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 $CaCO_3$) versus the average hardness of well plus de-ionized well water (100 mg/L $CaCO_3$), was applied to the starting DOC concentrations to achieve an estimate of the DOC concentrations at 100 mg/L $CaCO_3$). 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.

Table 9. Example Calculations to Estimate Water Chemistry of Tests Conducted at 100 mg/L $CaCO_3$ by Howarth and Sprague (1978) Using a Mixture of University of Guelph Well Water and De-ionized Water

Parameter (units in mg/L)	De-ionized water	Well Water	Example Calculations for Mixture
Hardness	0	366	100 (i.e., 0.27 dilution factor)
Ca	0	77 (from Dixon & Sprague 1981)	21
Mg	0	43 (from Dixon & Sprague 1981)	12
Na	14 (assuming NaCl used for the softening process)	14 (estimated from [Cl])	14
K	0	2.4 (based on personal communication from Dr. 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
Alkalinity (calculated using ratios as in Section 2.8):			
at pH 6	0[a]	81.5	22
at pH 7	0[a]	205	55
at pH 8	0[a]	250	N/A
at pH 9	0[a]	263	70

[a] 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 $CaCO_3$ 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_4, and Cl are needed for the following natural waters:

Water Body	Reference
American River, California – sand filtered	Finlayson and Verrue 1982
Clinch River – 11µm filtered	Belanger et al. 1989
	Belanger and Cherry 1990
Amy Bayou	Belanger and Cherry 1990
Blaine Creek, Kentucky – 1.6 µm filtered	Dobbs et al. 1994
S. Kawishiwi	Lind et al. manuscript
St. Louis River	Lind et al. manuscript
Lake One	Lind 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).

American River, CA (Appendix C-9). Source: Ron Myers, City of Sacramento, CA, Water Quality Laboratory

Applied to:	Hardness (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)	pH	DOC	Specific Ions (mg/L)						
					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

[a] DOC and K data for the American River were not available.

Clinch River, VA (Appendix D-5): Source: Don Cherry, VA Poly. Inst. & State Univ., Blacksburg,VA

Applied to:	Hardness (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)	pH	DOC	Specific Ions (mg/L)						
					Ca	Mg	Ca:Mg	Na	K	Cl	SO_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

Applied to:	Hardness (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)	pH	DOC	Specific Ions (mg/L) Ca	Mg	Ca:Mg	Na	K	Cl	SO_4
Lind et al. manuscript	24	18	6.6	-[a]	5.6	2.4	1.5	1.3	0.5	1.0	4.9

[a] 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

Applied to:	Hardness (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)	pH	DOC	Specific Ions (mg/L) Ca	Mg	Ca:Mg	Na	K	Cl	SO_4
Lind et al. manuscript	10	15	6.7	-[a]	2.8	0.7	1.8	0.1	0.3	0.2	4.2

[a] 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

Applied to:	Hardness (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)	pH	DOC	Specific Ions (mg/L) 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

[a] 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).

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

Applied to:	Hardness (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)	pH	DOC	Specific Ions (mg/L) 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[b]	1.4[c]	1.2	5.6

[a] 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).
[b] 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 $CaCO_3$ / 56 mg/L $CaCO_3$).
[c] 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).

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

Applied to:	Hardness (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)	pH	DOC	Specific Ions (mg/L) 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[b]	0.3[c]	1.7	7.6

[a] 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).
[b] 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 mg Na/L * (17 mg/L $CaCO_3$ / 10 mg/L $CaCO_3$).
[c] 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.

Green-Duwamish River, WA. Source: James Buckley

Applied to:	Hardness (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)	pH	DOC	Specific Ions (mg/L) Ca	Mg	Ca:Mg	Na	K	Cl	SO_4
Buckley 1983	33	29	7.2	3.2[a]	8.9	2.8	2.0	7.5	1.2	7.0	6.3

[a] 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

Applied to:	Hardness (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)	pH	DOC	Specific Ions (mg/L)						
					Ca	Mg	Ca:Mg	Na	K	Cl	SO_4
Carlson et al. 1986	39	20	6.4	3.7[a]	9.9	3.3	1.9	9.9	2.3	-	22

[a] 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

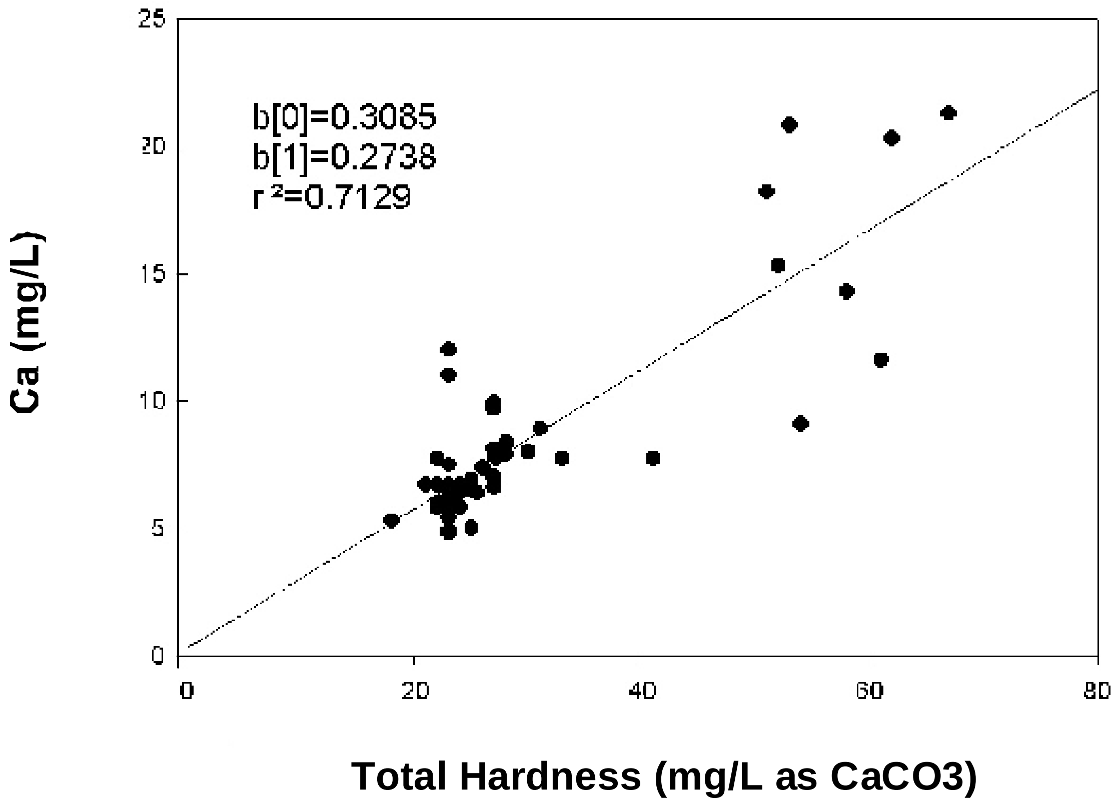


Figure 2. Relationship between Mg and hardness in WFTS well water.

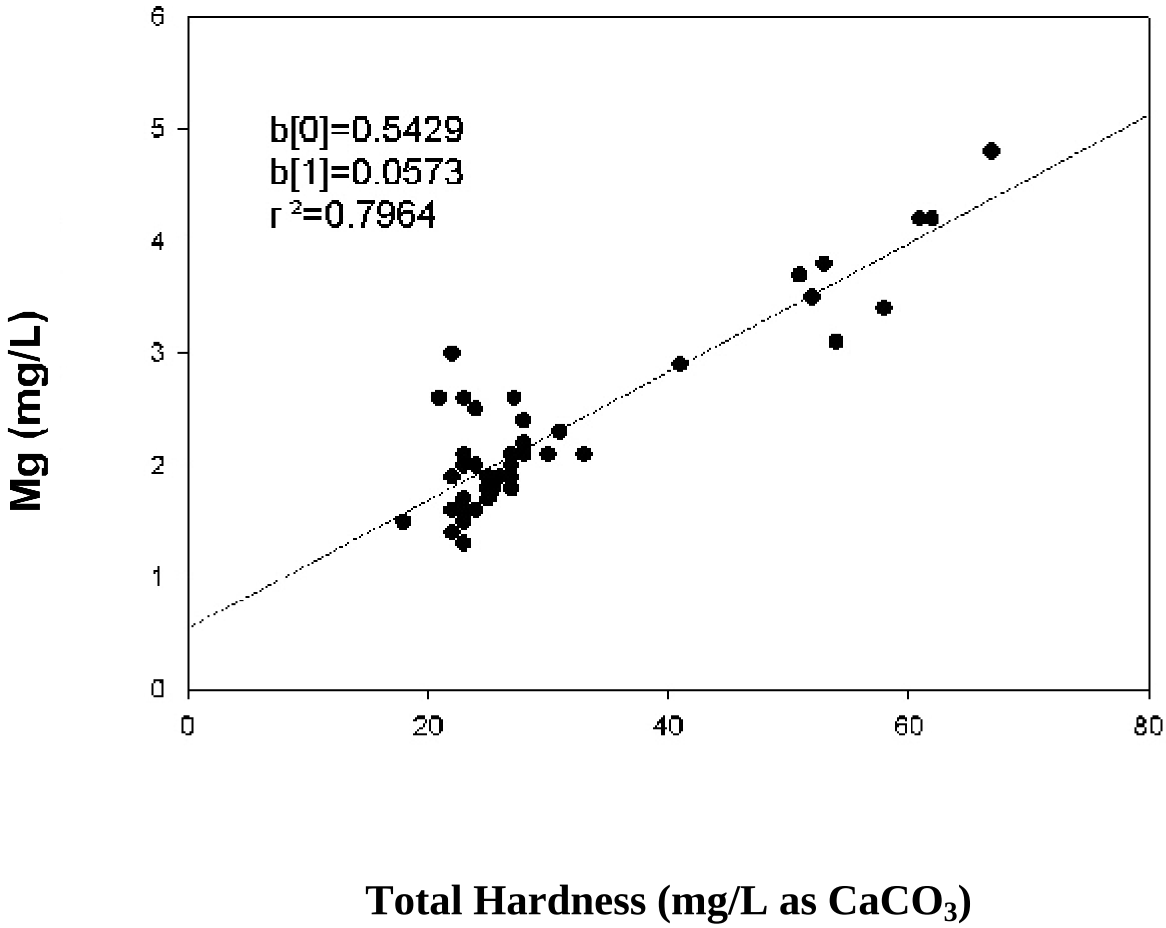


Figure 3. Relationship between Na and hardness in WFTS well water.

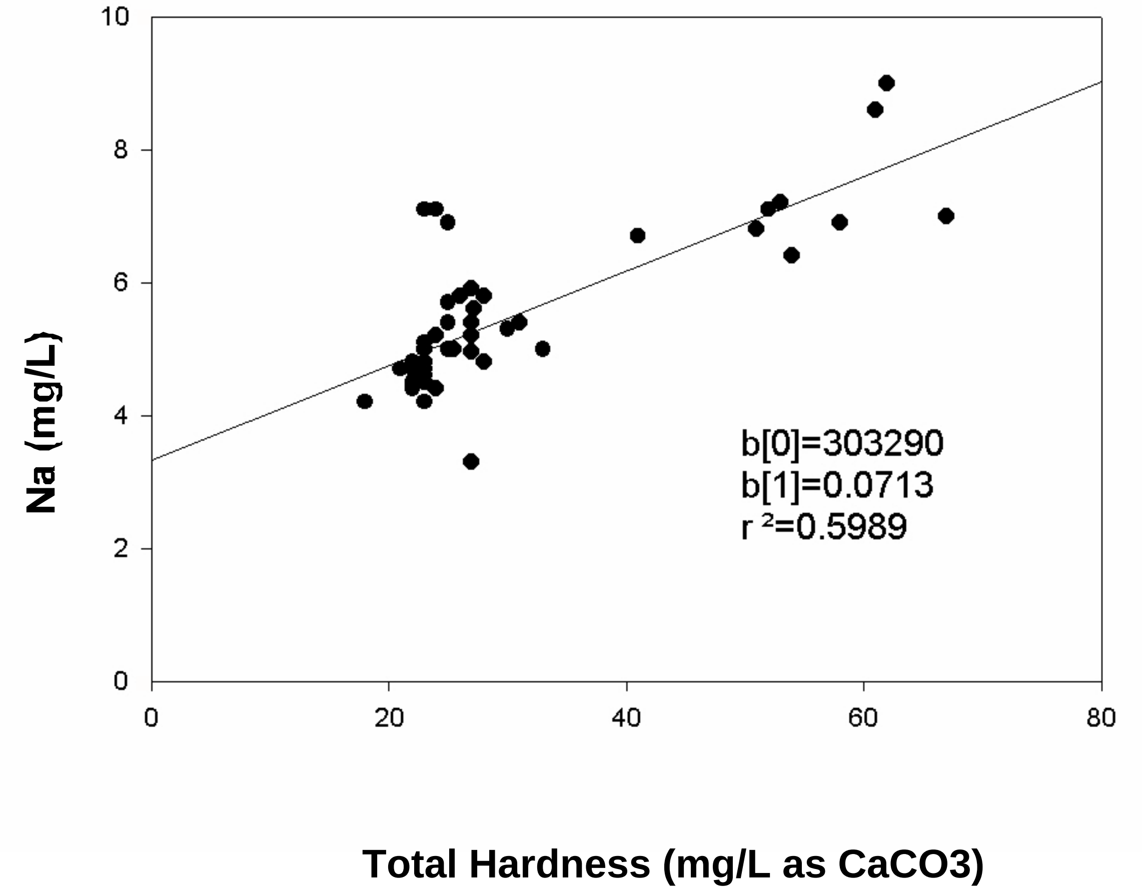


Figure 4. Relationship between K and hardness in WFTS well water

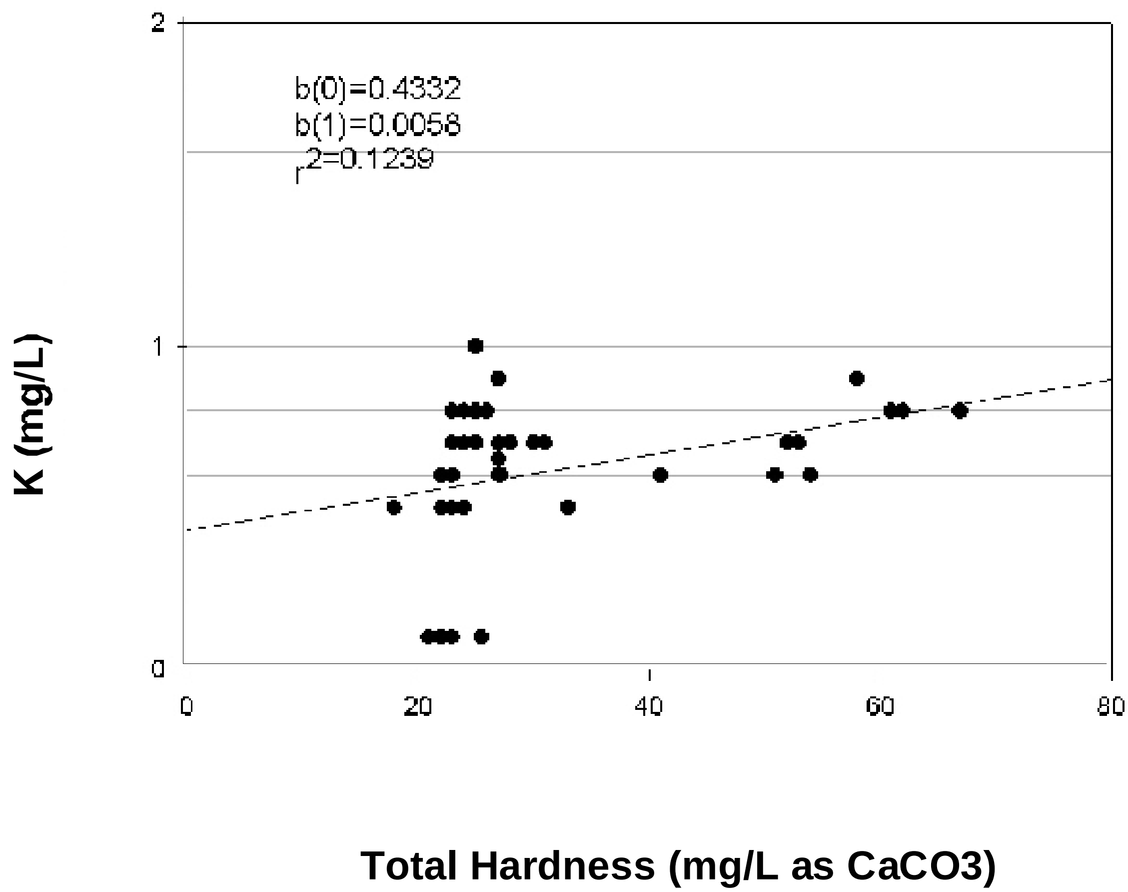


Figure 5. Relationship between Cl and hardness in WFTS well water.

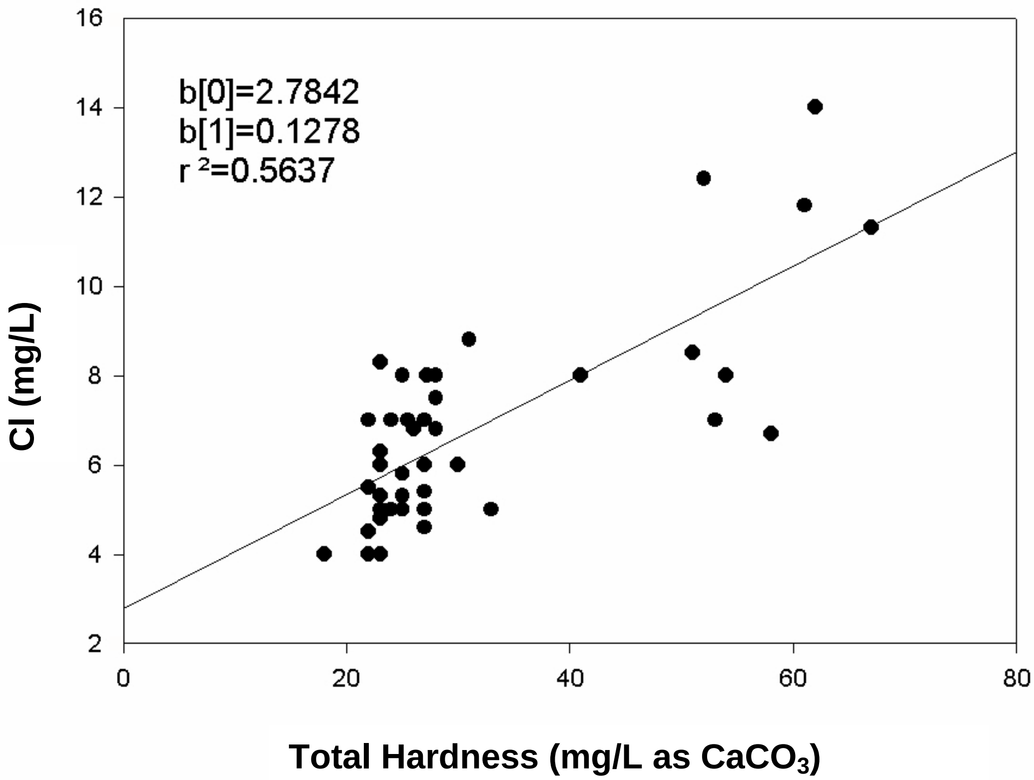


Figure 6. Relationship between SO_4 and hardness in WFTS well water.

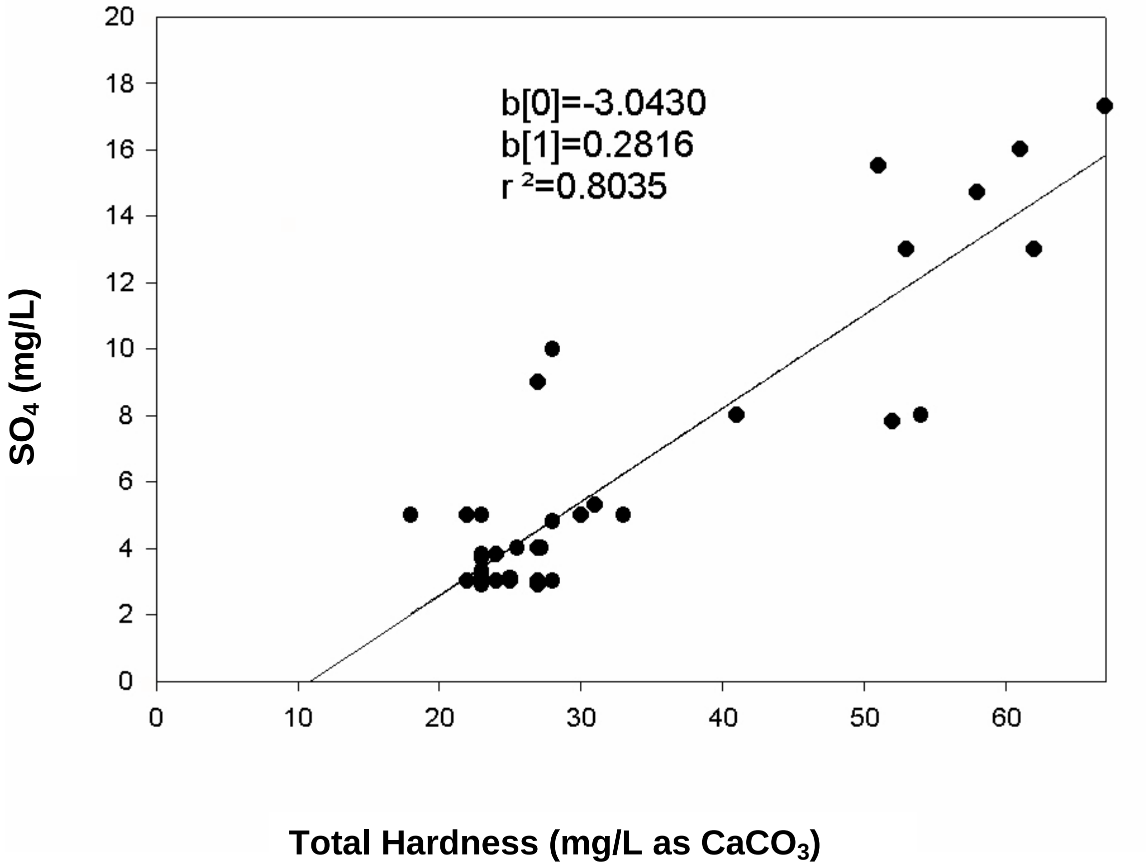


Figure 7. Slopes of the regression equations derived for Na concentration in St. Louis River, MN, water versus water hardness from 1973 to 1993.

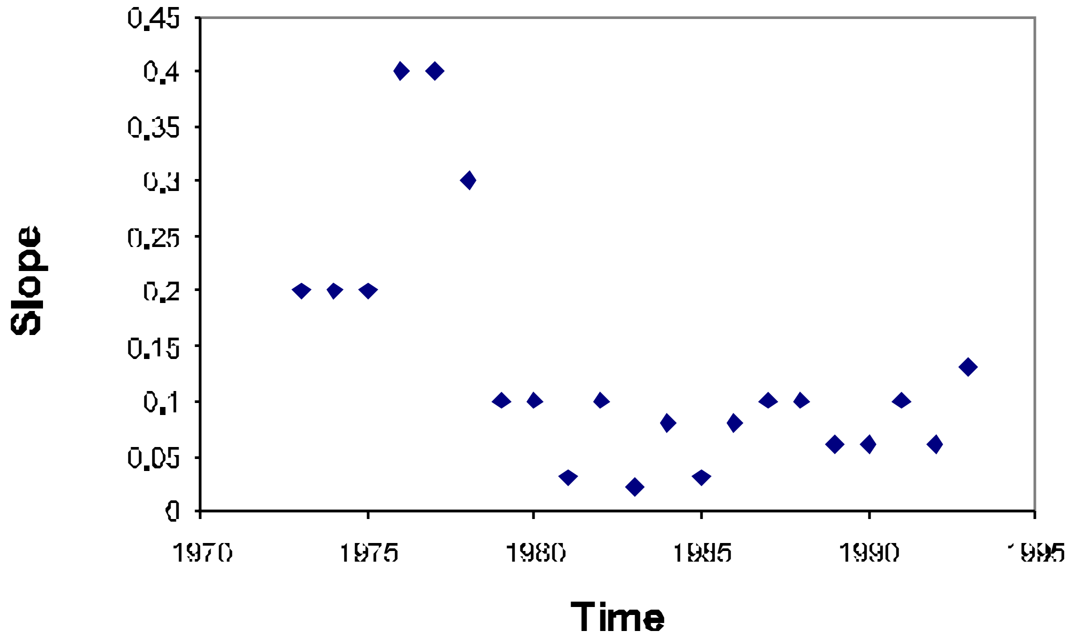
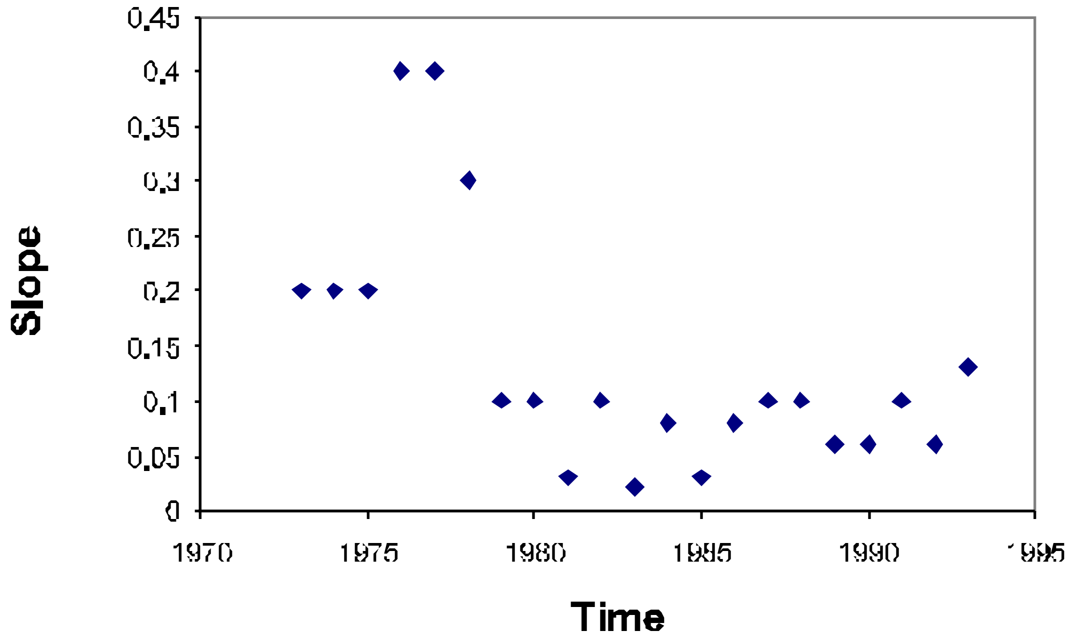


Figure 8. **Intercepts of the regression equations derived for Na concentration in St. Louis River, MN water versus water hardness from 1973 to 1993.**



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

Molecular Weights	Atomic Weights
$NaHCO_3$ = 84.03	Na = 22.98
$CaSO_4.2H_2 O$ = 172.12	Ca = 40.08
$MgSO_4$= 120.37	Mg = 24.31
KCl = 74.55	K = 39.10
SO_4 = 96.06	Cl = 35.45

Example Calculation

[Na] in very soft water:
12 mg $NaHCO_3$/L x 1 mmol $NaHCO_3$/84.03 mg $NaHCO_3$ = 0.143 mmol $NaHCO_3$/L.
0.143 mmol $NaHCO_3$/L x (1 mmol Na/1 mmol $NaHCO_3$) x 22.98 mg Na/1 mmol Na = 3.3 mg Na/L.

[Ca] in very soft water:
7.5 mg $CaSO_4$.2H2O/L x 1 mmol $CaSO_4.2H_2O$/172.12 mg $CaSO_4.2H_2O$ = 0.044 mmol $CaSO_4.2H_2O$/L.
0.044 mmol $CaSO_4.2H_2O$/L x (1 mmol Ca/1 mmol $CaSO_4.2H_2O$) x 40.08 mg Ca/1 mmol Ca = 1.8 mg Ca/L.

[Mg] in very soft water:
7.5 mg $MgSO_4$/L x 1 mmol $MgSO_4$/120.37 mg $MgSO_4$ = 0.062 mmol $MgSO_4$/L.
0.062 mmol $MgSO_4$/L x (1 mmol Mg/1 mmol $MgSO_4$) 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] in very soft water:
7.5 mg $CaSO_4.2H_2O$/L x 1 mmol $CaSO_4.2H_2 O$/172.12 mg $CaSO_4.2H_2O$ = 0.044 mmol $CaSO_4.2H_2O$/L.
0.044 mmol $CaSO_4.2H_2O$/L x (1 mmol SO_4/1 mmol $CaSO_4.2H_2O$) x 96.064 mg Ca/1 mmol Ca = 4.2 mg Ca/L.

[SO_4] in very soft water:
7.5 mg $MgSO_4$/L x 1 mmol $MgSO_4$/120.37 mg $MgSO_4$ = 0.062 mmol $MgSO_4$/L.
0.062 mmol $MgSO_4$/L x (1 mmol SO_4/1 mmol $MgSO_4$) x 96.064 mg Mg/1 mmol Mg = 6.0 mg Mg/L.

Total SO_4 = 10.2 mg/L

Conversion Factors to calculate water hardness (as $CaCO_3$) from [Ca] and [Mg]:

[Ca] x 2.497
[Mg] x 4.116

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
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	---	---	---	---
CT	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
KY	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
MO	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	---	---	---	---
TX	1.33	6.5	7.83	83.01	1.55	10.3	11.85	86.92
UT^	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	---	---	---	---

			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.

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

	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 experiment TOC	a	1.13	1.34	1.26
	b	1.37	1.30	1.36
	Mean	1.25	1.32	1.31
Post-gill experiment TOC	a	1.20	1.24	1.18
	b	1.27	1.46	1.10
	Mean	1.24	1.35	1.14
Pre-gill experiment DOC	a	1.96	1.51	1.34
	b	1.52	1.28	0.99
	Mean	1.74	1.40	1.17
Post-gill experiment DOC	a	1.49	1.36	1.44
	b	1.64	1.58	1.24
	Mean	1.57	1.47	1.34

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

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	K	SO_4	Cl
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

Month	Total Hardness	Ca	Mg	Na	K	SO_4	ClD
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	pH	Hardness	Alkalinity	Ca	Mg	Na	K	Cl	SO_4	NO_3	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		
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	
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	

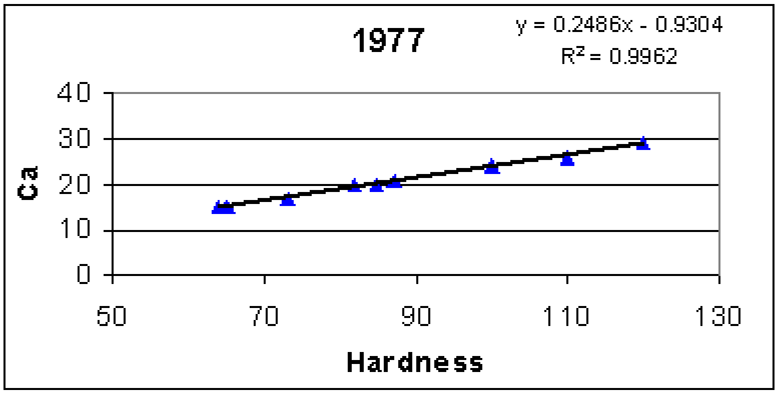
Appendix C-6. Water Composition of St. Louis River, MN, from USGS NASQAN and Select Relationships to Water Hardness

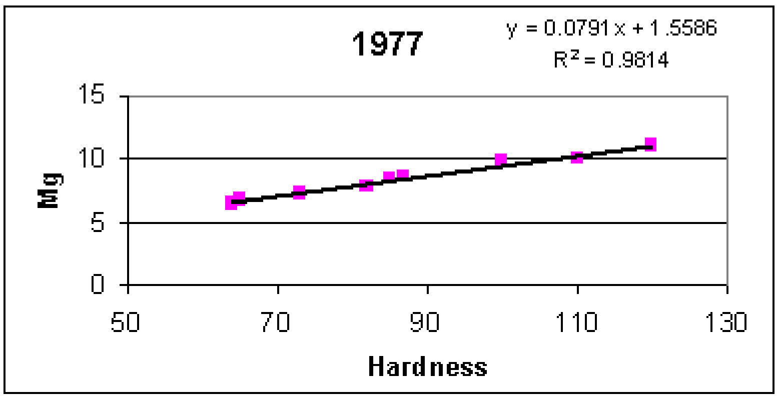
Date	pH	Hardness	Alkalinity	Ca	Mg	Na	K	Cl	SO_4	NO_3	DOC
19730222	6.8	68	53	17	6.3	11	1.6	14	14	0.19	
19730503	7.1	58	46	14	5.5	6.6	1.1	9.5	13	0.17	
19730816	6.9	70	51	17	6.6	7.6	1.2	9	20	0.01	
19731128	7	65	48	16	6.1	7.5	1.3	8.8	14		
19740221	7	64	48	16	5.8	8.9	1.3	12	14		
19740516	6.9	45	32	11	4.3	3.5	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		
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		
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		
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

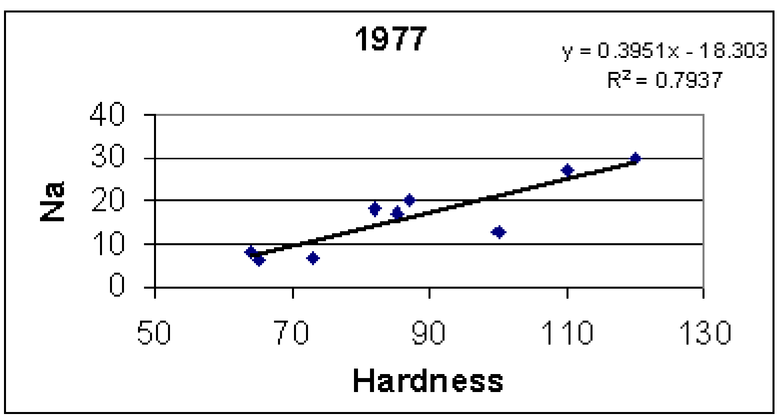
Date	pH	Hardness	Alkalinity	Ca	Mg	Na	K	Cl	SO_4	NO_3	DOCD
19790329	7.6	80	63	19	8	8.4	2.3	7.8	13		
19790430	7.6	37	29	8.7	3.7	2.2	1.3	2.8	8.9		20
19790611	7.2	47	34	11	4.8	3.1	0.8	2.8	9.4		
19790723	7.6	73	55	17	7.3	3.9	0.9	3.7	8.9		30
19790827	7.2										
19791015	8.1	74	54	16	8.2	5	1.1	3.9	13	0.01	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	
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	

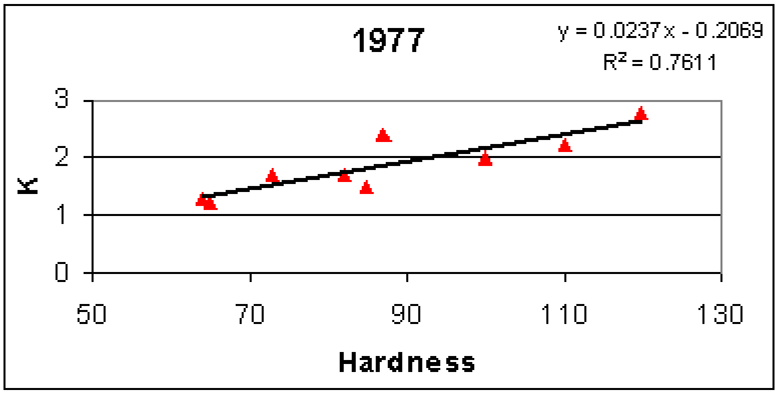
Date	pH	Hardness	Alkalinity	Ca	Mg	Na	K	Cl	SO_4	NO_3	DOCD
19851203	7.4	73		16	8	4	1	4.2	18	0.16	
19860303	7.4	66		15	7	4	1	3.4	10	0.24	
19860407	7.3									0.19	
19860602	7.5	58		13	6.3	3.5	1	2.8	15	0.1	
19860818	7.9	74		15	8.9	4.6	1.2	3.7	24	0.1	
19861112	7.5	55		12	6	3.4	1.4	3.8	19	0.27	
19861210	7.3	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	27	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		20	11	7.8	1.5	7.9	20	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	1.3	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										
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	9.1	7.3	1.2	7.3	12	0.28	
19930426	7.7	66		15	6.8	4.1	1.2	4.9	9.5	0.092	
19930722	7.5	64		15	6.5	4	0.2	3.9	7.7	0.079	
19931201	7.7	80		17	9	4.8	1	4	11	0.16	

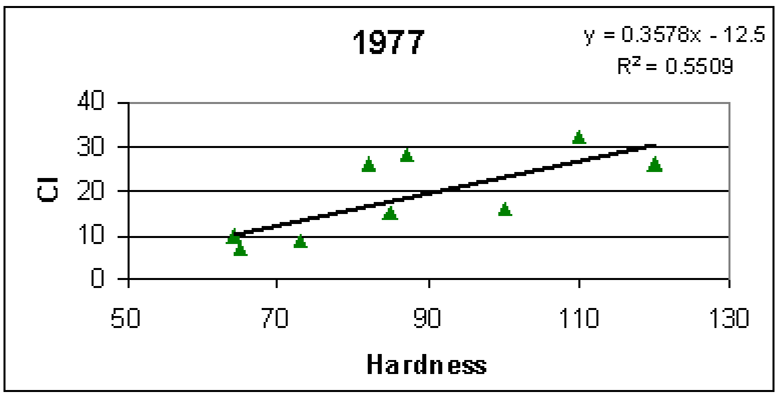
Date	pH	Hardness	Alkalinity	Ca	Mg	Na	K	Cl	SO_4	NO_3	DOCD
19940216	7.3										
19940511	7.7	51		11	5.6	3.7	1.1	3.4	9.4	0.076	
MIN	6.4	30	25	7.5	2.5	2.1	0.2	0.2	3.8	0.01	10
MAX	9.5	130	110	29	15	30	8.5	32	36	0.37	37
MEAN	7.52	71.11	56.94	16.16	7.46	7.09	1.37	7.39	15.04	0.17	22.19

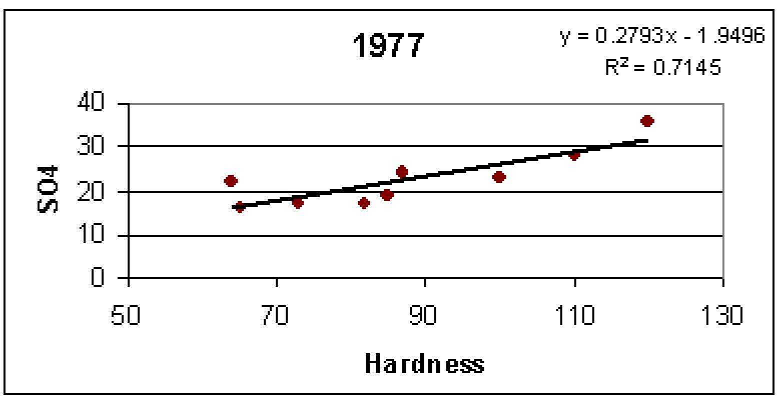

1977
y = 0.2486x - 0.9304
R² = 0.9962
40
30
20
10
0
Ca
50
70
90
110
130
Hardness


1977
y = 0.0791x + 1.5586
R² = 0.9814
15
10
5
0
Mg
50
70
90
110
130
Hardness


1977
y = 0.3951x - 18.303
R² = 0.7937
40
30
20
10
0
Na
50
70
90
110
130
Hardness


1977
y = 0.0237x - 0.2069
R² = 0.7611
K
0
1
2
3
50
70
90
110
130
Hardness


1977
y = 0.3578x - 12.5
R² = 0.5509
Cl
0
10
20
30
40
50
70
90
110
130
Hardness


1977
y = 0.2793x - 1.9496
R² = 0.7145
SO4
0
10
20
30
40
50
70
90
110
130
Hardness

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

Tank	Dose (µg Cu/L)	Conductivity (µmho/cm)	pH	Oxygen (mg/L)	Temp (°C)	Alkalinity (as mg $CaCO_3$/L)	Hardness (as mg $CaCO_3$/L)
***0 hours* 7/9/92**							
a	897	325	8.62	7.5	21	100	96
b	897	300	8.6	7.6	21	100	96
c	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
I	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
l	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
o	319	320	8.67	7.7	21	80	96
p	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
***24 hours* 7/10/92**							
a	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
I	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
l	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
o	319	310	7.79	8.7	22.5	80	100
p	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
***48 hours* 7/11/92**							
a	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

Tank	Dose (µg Cu/L)	Conductivity (µmho/cm)	pH	Oxygen (mg/L)	Temp (°C)	Alkalinity (as mg $CaCO_3$/L)	Hardness (as mg $CaCO_3$/L)D
h	93	300	8.13	7.7	21	100	100
I	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
l	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
o	319	310	8.18	7.3	22	100	96
p	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
***72 hours* 7/12/92**							
a	897	*	*	*	*	*	*
b	897	*	*	*	*	*	*
c	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
I	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
l	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
o	319	320	7.99	8.8	22	100	104
p	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
***96 hours* 7/13/92**							
a	897	*	*	*	*	*	*
b	897	*	*	*	*	*	*
c	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
I	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
l	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
o	319	330	8.08	7.3	22	100	104

Tank	Dose (µg Cu/L)	Conductivity (µmho/cm)	pH	Oxygen (mg/L)	Temp (°C)	Alkalinity (as mg $CaCO_3$/L)	Hardness (as mg $CaCO_3$/L)D
p	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.

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

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
pH	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 $CaCO_3$)	164-180	152-166	152-168	148-170	164-174	162-172	164-168	162-172
Alkalinity (mg/l $CaCO_3$)	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-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.

Date	pH	Hardness	Alkalinity	Ca	Mg	Ca:Mg	Na	Cl	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-10. STORET Data for Minnesota Lakes and Rivers

Date	pH	Hardness	Alkalinity	Ca	Mg	Ca:Mg	Na	K	Cl	SO_4	NO_3	TOC	DOC	Sulfide
Embarrass River, MN														
3/22/76	7	133	103	27	16	1.69	2.5	2	11	34				
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				
6/28/76	6.9	44	36	9.9	4.6	2.15	3.9	0.3	5	13	0.04	37		
7/28/76	6.6		76	5.2					4.8	7.5				
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
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	2.5	2.20	1.2	0.4	0.6	4.1				
12/11/75		39	23	10	3.4	2.94	1.4	0.4	1.5					0.2
1/9/76	6.6	29	24	6.2	3.2	1.94	1.6	0.8	2.3	7				
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
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				
6/25/76	6.6		16						1.1	3.3				1.8
7/23/76	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	8.5	56	33	13	5.7	2.28	4.3	1.5	6.3	22	0.25	17		
6/17/96	6.8										0.25	17		
6/17/96	6.9	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											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		

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
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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 dissolved-to-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-to-nominal 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 µg/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 mussel tests were 0.836 and 0.785, respectively. 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 ± 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, *Mytilus sp*	0.863	0.906	SAIC 1993
Blue mussel, *Mytilus edulis*	0.979	0.879	CH2MHill 1999b
Blue mussel, *Mytilus sp*	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	±0.056	±0.082	

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Appendix E. BLM Input Data and Notes

	Model Output		Model Input													
BLM Data Label	Critical Accumulation	Hard-ness (mg/L)	Temp (ºC)	pH	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
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

Appendix E. BLM Table

	Model Output		Model Input													
BLM Data Label	Critical Accumulation	Hard-ness (mg/L)	Temp (ºC)	pH	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
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

Appendix E. BLM Table

	Model Output		Model Input													
BLM Data Label	Critical Accumulation	Hard-ness (mg/L)	Temp (ºC)	pH	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
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

Appendix E. BLM Table

	Model Output		Model Input													
BLM Data Label	Critical Accumulation	Hard-ness (mg/L)	Temp (ºC)	pH	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

Appendix E. BLM Table

	Model Output		Model Input													
BLM Data Label	Critical Accumulation	Hard-ness (mg/L)	Temp (ºC)	pH	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
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

Appendix E. BLM Table

BLM Data Label	Model Output: Critical Accumulation	Hard-ness (mg/L)	Model Input: Temp (ºC)	pH	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
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

Appendix E. BLM Table

BLM Data Label	Model Output: Critical Accumulation	Hard-ness (mg/L)	Model Input: Temp (ºC)	pH	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
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

Appendix E. BLM Table

BLM Data Label	Model Output: Critical Accumulation	Hard-ness (mg/L)	Model Input: Temp (ºC)	pH	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
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

Appendix E. BLM Table

BLM Data Label	Model Output	Hard-ness (mg/L)	Model Input													Notes
	Critical Accumulation		Temp (ºC)	pH	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)	
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

Appendix E. BLM Table

BLM Data Label	Model Output: Critical Accumulation	Hard-ness (mg/L)	Model Input: Temp (ºC)	pH	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
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

Appendix E. BLM Table

BLM Data Label	Model Output: Critical Accumulation	Hard-ness (mg/L)	Model Input: Temp (ºC)	pH	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.

Probability Distribution Analysis

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

Logistic Regression Analysis

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

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 µg/L total copper (NOAEC) and 5.0 µg/L total copper (LOAEC). The chronic value determined via traditional hypothesis testing is 3.54 µg/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 µg/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 µg/L total copper were obtained for survival based on the geometric mean of the NOAEC and LOAEC of 8.0 and 14.8 µg/L, respectively, in both tests. The corresponding EC20s were 8.73 and 10.94 µg/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 µg/L (5 to 10 µg/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 µg/L total copper (27 µg/L dissolved copper). No daphnids survived to produce young at 91 µg/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 µg/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 $CaCO_3$, 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 µg/L dissolved copper, respectively. The EC20 value for number of young (neonates) produced in Clinch River water (water hardness of 94 mg/L as $CaCO_3$) was 19.36 µg/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 µg/L, respectively.

Copper was one of 12 toxicants examined by Oris et al. (1991) in their comparisons between a 4-day 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 µg/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 µg/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 µg/L total copper. The chronic value determined for this study (17.32 µg/L total copper) was based on the geometric mean of the NOAEC, 10 µg/L, and LOAEC, 30 µg/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 $CaCO_3$. Carapace length was significantly reduced at 36.8 µg/L total copper, although survival was 100 percent at this concentration. Carapace length was not affected at 12.6 µg/L total copper. No daphnids survived at 110 µg/L concentration. The highest concentration not significantly different from the control for survival was 36.8 µg/L. The lowest concentration significantly different from the control based on survival was 110 µg/L, resulting in a chronic value of 63.6 µg/L for survival. The chronic value based on carapace length was 21.50 µg/L. The 21-day EC10 as reported by the author was 5.9 µg/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 $CaCO_3$, 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 $CaCO_3$, and 80 percent at a hardness of 100 mg/L as $CaCO_3$. 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 $CaCO_3$, 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 $CaCO_3$, but slightly increased from 100 to 200 mg/L as $CaCO_3$.

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 µg/L total copper at hardnesses of 57.5, 115, and 230 (0.15 mg/L HA) µg/L as $CaCO_3$, respectively. The EC20 values calculated for the low and high hardness studies using nonlinear regression techniques were 2.83 and 9.16 µg/L at hardness values of 57.5 and 230 (0.15 mg/L HA) µg/L as $CaCO_3$, 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 µg/L total copper from first-generation larvae. No observed adverse effect to adult emergence occurred at 8.3 µg/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 µg/L total copper. The corresponding EC20 value for adult emergence was 7.67 µg/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 post-fertilization, 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 $CaCO_3$. 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 µg/L, respectively (geometric mean = 22.27 µg/L). The EC20 for biomass for the continuous exposure was 27.77 µg/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 µg/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 $CaCO_3$. 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 µg/L, respectively. Copper adversely affected survival at 11.7 µg/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 µg/L. The EC20 value estimated for biomass is 5.92 µg/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 µg/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 µg/L total copper (geometric mean of 20.8 and 43.8 µg/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 $CaCO_3$; hardwater at 187 mg/L as $CaCO_3$) 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 $CaCO_3$. 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 µg/L. The resultant chronic value for soft water based on hypothesis testing was <5 µg/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 embryo-larval 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 µg/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 µg/L total copper (geometric mean of 22.3 and 43.5 µg/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 µg/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 µg/L total copper (geometric mean of 22.0 and 43.5 µg/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 µg/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 µg/L total copper (geometric mean of 34.9 and 104.4 µg/L total copper).

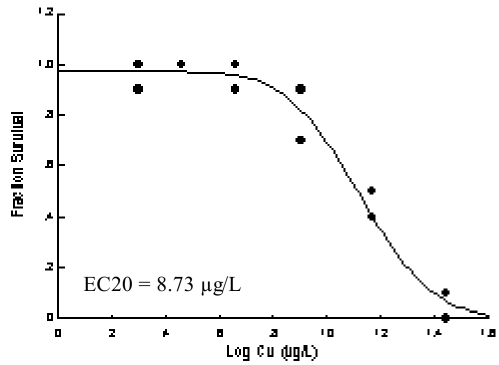
Pimephales notatus. An experimental design similar to that described by Mount and Stephan (1967) and Mount (1968) was used to examine the chronic effect of copper on the bluntnose minnow, *P. notatus* (Horning and Neiheisel 1979). Measured total copper concentrations were 4.3 (control), 18.0, 29.9, 44.1, 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 $CaCO_3$. 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_1) 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 µg/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 µg/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 $CaCO_3$) 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 was not affected by total copper concentrations as high as 52.1 µg/L total copper. Survival after hatch, however, was compromised at 26.2 µg/L, and mean wet weight of juvenile fathead minnows was significantly reduced at 13.1 µg/L of copper. The estimated EC20 value for biomass was 9.376 µg/L total copper.

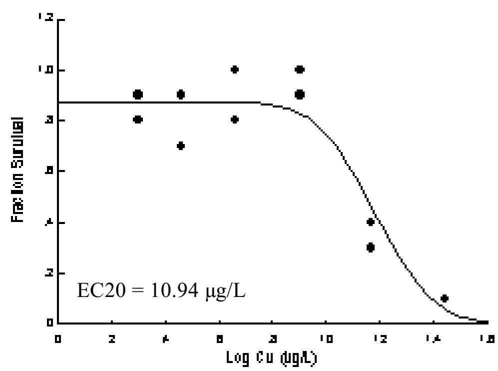
Catastomus commersoni. McKim et al. (1978) examined the survival and growth (expressed as standing crop) of embryo-larval and early juvenile white sucker exposed to copper. The embryo exposure was for 13 days, and the larval-early-juvenile exposure lasted 27 days. The NOAEC and LOAEC were 12.9 and 33.8 µg/L total copper, respectively. The resulting chronic value based on hypothesis testing for this species was 20.88 µg/L total copper (geometric mean of 12.9 and 33.8 µg/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 $CaCO_3$). 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 µg/L, respectively. In the 22-month juvenile through adult exposure, survival, growth, and reproduction were unaffected at 77 µg/L of copper and below. No spawning occurred at 162 µg/L. Embryo hatchability and survival of 4-day-old larvae at 77 µg/L did not differ significantly from those of controls. However, after 90 days of exposure, survival of larval *L. macrochirus* at 40 and 77 µg/L was significantly lower than for controls, and no larvae survived at 162 µg/L. Growth remained unaffected at 77 µg/L. Based on the 90-day survival of bluegill larvae, the chronic limits were estimated to be 21 and 40 µg/L (geometric mean = 28.98 µg/L). The corresponding EC20 for embryo-larval survival was 27.15 µg/L.

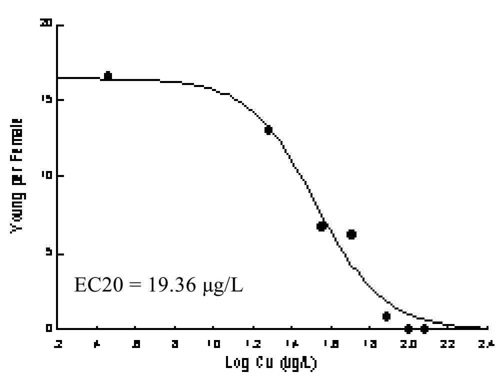
Campeloma decisum **(Test 1), Life-cycle, Arthur and Leonard 1970**



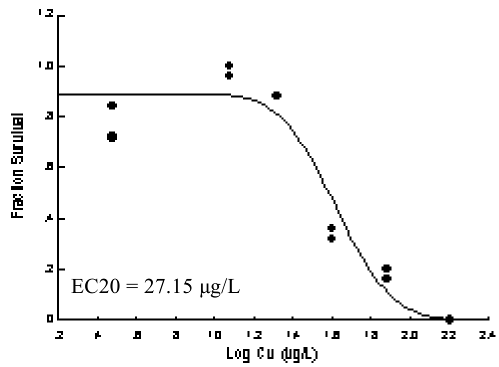
Campeloma decisum **(Test 2), Life-cycle, Arthur and Leonard 1970**



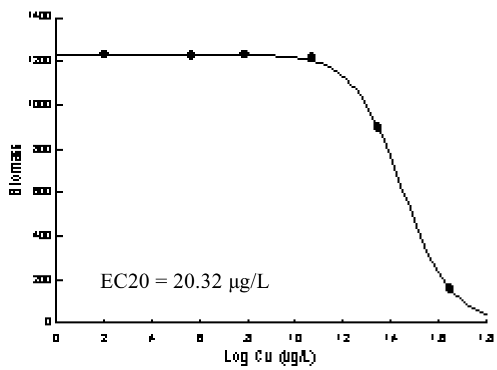
Ceriodaphnia dubia **(Clinch River), Life-cycle, Belanger et al. 1989**



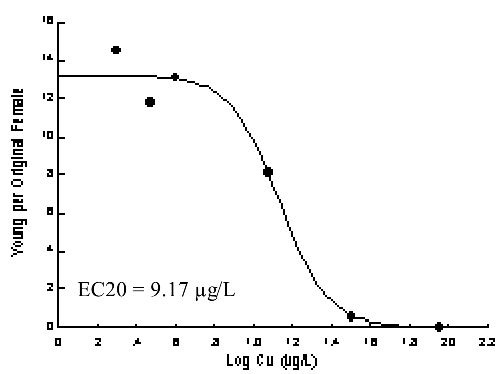
***Lepomis macrochirus*, Early Life-stage, Benoit 1975**



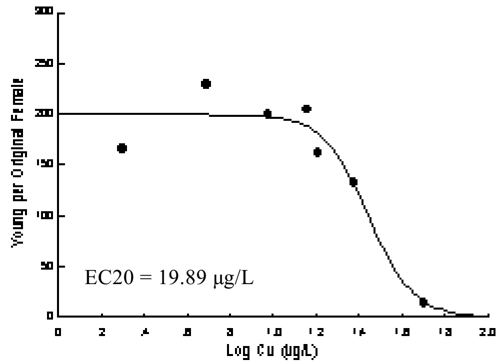
***Oncorhynchus mykiss*, Early Life-Stage, Besser et al. 2001**



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



***Daphnia magna* (Hardness 104), Life-cycle, Chapman et al. Manuscript**



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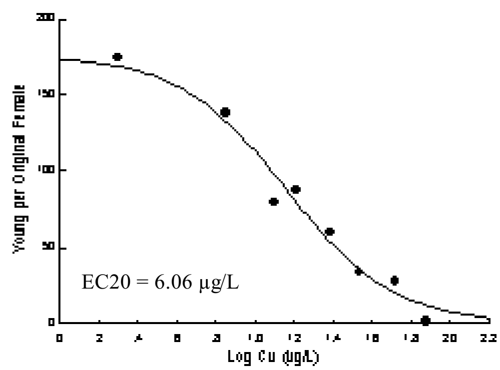
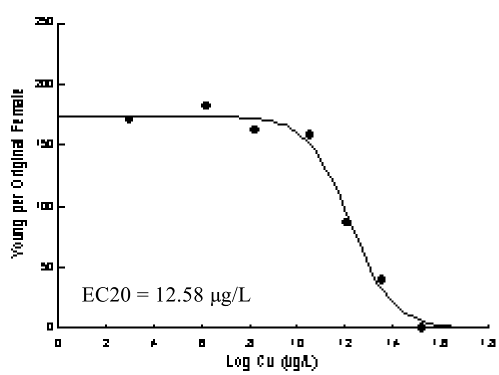
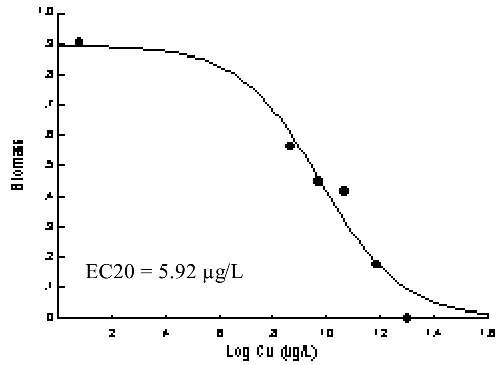


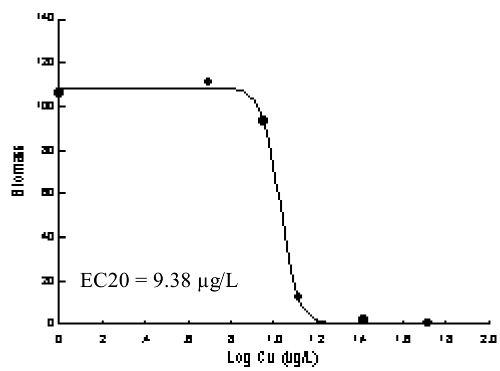
***Daphnia magna* (Hardness 51), Life-cycle, Chapman et al. Manuscript**



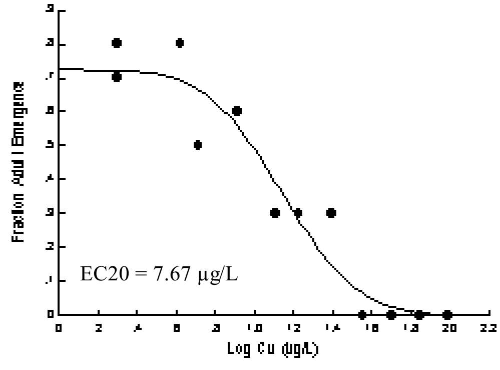
***Oncorhynchus tshawytscha*, Early Life-Stage, Chapman 1975 & 1982**



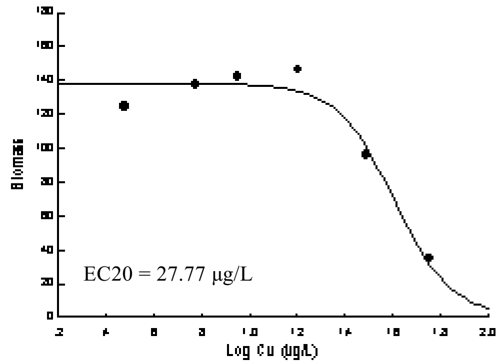
***Pimephales promelas*, Early Life-stage, Lind et al. 1978**



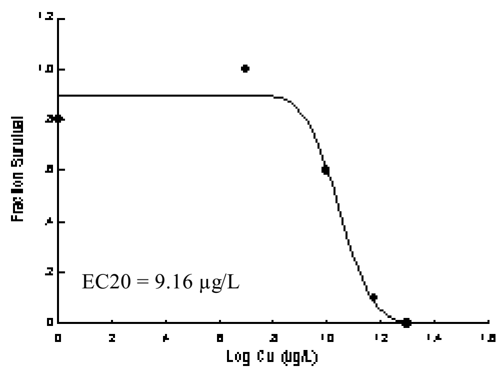
***Clistoronia magnifica*, Life-cycle, Nebeker et al. 1984a**



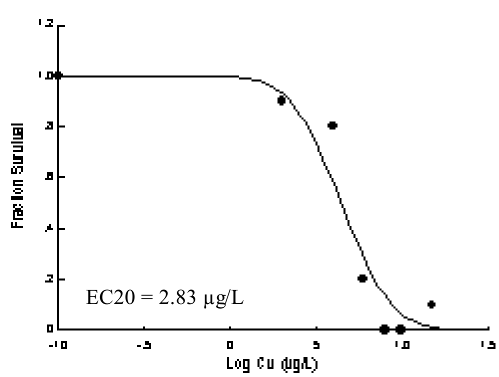
Oncorhynchus mykiss, Early Life-stage, Seim et al. 1984



***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.

pH	Hardness	DOC	Hardness Equation Based Water Quality Criterion for Cu[1]	BLM Based Instantaneous Water Quality Criterion for Cu
	mg/L $CaCO_3$	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

pH	Hardness	DOC	Hardness Equation Based Water Quality Criterion for Cu[1]	BLM Based Instantaneous Water Quality Criterion for Cu
	mg/L $CaCO_3$	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
		16	11.3	125.1
	159	2	21.7	18.0
		4	21.7	35.3
		8	21.7	70.3
		16	21.7	142.0
	317	2	41.5	21.5
		4	41.5	41.6
		8	41.5	82.3
		16	41.5	165.1

pH	Hardness	DOC	Hardness Equation Based Water Quality Criterion for Cu[1]	BLM Based Instantaneous Water Quality 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: $\boldsymbol{CMC} = \boldsymbol{e}^{(0.9422\,[\ln(H)]\,-\,1.7)}$

where:
H = water hardness (mg/L $CaCO_3$)

* 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

Abalde et al. (1995)
Abel (1980)
Ahsanullah and Ying (1995)
Ahsanullah et al. (1981)
Aoyama and Okamura (1984)
Austen and McEvoy (1997)
Bougis (1965)
Cid et al. (1995, 1996a,b)
Collvin (1984)
Cosson and Martin (1981)
Daly et al. (1990a,b, 1992)
Denton and Burdon-Jones (1986)
Drbal et al. (1985)
Giudici and Migliore (1988)
Giudici et al. (1987, 1988)
Gopal and Devi (1991)
Gustavson and Wangberg (1995)
Hameed and Raj (1989)
Heslinga (1976)
Hori et al. (1996)
Huebner and Pynnonen (1992)
Ismail et al. (1990)
Jana and Bandyopadhyaya (1987)
Jindal and Verma (1989)
Jones (1997)
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. (1980)
Paulij et al. (1990)
Peterson et al. (1996)
Pistocchi et al. (1997)
Pynnonen (1995)
Raj and Hameed (1991)
Rajkumar and Das (1991)
Reeve et al. (1977)
Ruiz et al. (1994, 1996)
Saward et al. (1975)
Schafer et al. (1993)
Smith et al. (1993)
Solbe and Cooper (1976)
Steeman-Nielsen and Bruun-Laursen (1976)
Stephenson (1983)
Takamura et al. (1989)
Taylor et al. (1991, 1994)
Timmermans (1992)
Timmermans et al. (1992)
Vardia et al. (1988)
Verriopoulos and Moraitou-Apostolopoulou (1982)
Visviki and Rachlin (1991)
Weeks and Rainbow (1991)
White and Rainbow (1982)
Wong and Chang (1991)
Wong et al. (1993)

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

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

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Environmental Protection
Agency

Office of Water
4301

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1995 Updates:

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

PETITIONERS' EXHIBIT 11

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.

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INTRODUCTION

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:

ACR = Acute-Chronic Ratio
CCC = Criterion Continuous Concentration
CMC = Criterion Maximum Concentration
FAV = Final Acute Value
FCV = Final Chronic Value
GMAV = Genus Mean Acute Value
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 Arsenic(III)

The new acceptable acute and chronic data for arsenic(III) are given in Tables A1 and A2. These new data were used with those given in Tables 1 and 2 of the criteria document for arsenic (U.S. EPA 1985) to obtain the values given in Table A3.

Criterion Maximum Concentration (CMC)

The Final Acute Value (FAV) was calculated using the four lowest Genus Mean Acute Values given in Table A3, resulting in a FAV of 679.6 ug/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 339.8 ug/L, as total recoverable arsenic(III).

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 3.784; the geometric mean of this value and the ACR in U.S. EPA (1985) for the same species was 4.199. This and the two other Species Mean ACRs in U.S. EPA (1985) are given in Table A3; the three ACRs were within a factor of 1.2. The FACR was calculated as the geometric mean of the three ACRs and was 4.594. The FCV = FAV/FACR = (679.6 ug/L)/(4.594) = 147.9 ug/L. This value did not need to be lowered to protect a commercially or recreationally important species. The CCC was 147.9 ug/L, as total recoverable arsenic(III).

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 arsenic(III) does not exceed 147.9 ug/L more than once every three years on the average and if the one-hour average concentration does not exceed 339.8 ug/L more than once every three years on the average.

Table A1. New Acute Values for Arsenic(III)

Species	Method*	Chemical	Test Duration (hrs)	Acute Value (ug/L)	Reference
Fathead minnow, Pimephales promelas	FT,M	Sodium arsenite	96	12,600	Spehar and Fiandt 1986
Cladoceran, Daphnia magna	S,U	Sodium arsenite	48	4,501	Elnabarawy et al. 1986
Cladoceran, Daphnia pulex	S,U	Sodium arsenite	48	2,366	Elnabarawy et al. 1986
Cladoceran, Ceriodaphnia reticulata	S,U	Sodium arsenite	48	1,269	Elnabarawy et al. 1986

* FT = flow-through, M = measured, S = static, U = unmeasured.

Table A2. New Chronic Values for Arsenic(III)

Species	Test*	Acute Value (ug/L)	Chronic Value (ug/L)	Acute-Chronic Ratio	Reference
Fathead minnow, Pimephales promelas	ELS	12,600	3,330	3.784	Spehar and Fiandt 1986

* ELS = early life stage.

Table A3. Ranked Genus Mean Acute Values for Arsenic(III)

Rank*	Genus Mean Acute Value (ug/L)	Species	Species Mean Acute Value (ug/L)	Species Mean Acute-Chronic Ratio
14	97,000	Midge, Tanytarsus dissimilis	97,000	-----
13	41,760	Bluegill, Lepomis macrochirus	41,760	-----
12	26,040	Goldfish, Carassius auratus	26,040	-----
11	24,500	Snail, Aplexa hypnorum	24,500	-----
10	22,040	Stonefly, Pteronarcys californica	22,040	-----
9	20,130	Flagfish, Jordanella floridae	20,130	4.862
8	18,100	Channel catfish Ictalurus punctatus	18,100	-----
7	14,960	Brook trout, Salvelinus fontinalis	14,960	-----
6	14,065	Fathead minnow, Pimephales promelas	14,065	4.199
5	13,340	Rainbow trout, Oncorhynchus mykiss	13,340	-----
4	2,690	Cladoceran, Daphnia magna	4,449	4.748
		Cladoceran, Daphnia pulex	1,626	-----
3	1,511	Cladoceran, Ceriodaphnia reticulata	1,511	-----
2	1,175	Cladoceran, Simocephalus serrulatus	812	-----
		Cladoceran, Simocephalus vetulus	1,700	-----
1	874	Amphipod, Gammarus pseudolimnaeus	874	-----

* Ranked from most resistant to most sensitive based on Genus Mean Acute Value.

FAV = 679.6 ug/L

CMC = FAV/2 = 339.8 ug/L

FACR = 4.594

FCV = FAV/FACR = (679.6 ug/L)/(4.594) = 147.9 ug/L = CCC

References

Elnabarawy, M.T., A.N. Welter, and R.R. Robideau. 1986. Relative Sensitivity of Three Daphnid Species to Selected Organic and Inorganic Chemicals. Environ. Toxicol. Chem. 5:393-398.

Spehar, R.L., and J.T. Fiandt. 1986. Acute and Chronic Effects of Water Quality Criteria-based Metal Mixtures on Three Aquatic Species. Environ. Toxicol. Chem. 5:917-931.

U.S. EPA. 1985. Ambient Water Quality Criteria for Arsenic - 1984. EPA 440/5-84-033. National Technical Information Service, Springfield, VA.

1995 UPDATE: Freshwater Aquatic Life Criterion for Cadmium

The new acceptable acute and chronic data for cadmium are given in Tables B1 and B2. These new data were used with those given in Tables 1 and 2 of the criteria document for cadmium (U.S. EPA 1985) to obtain the values given in Tables B3 and B4. Because the toxicity of cadmium is hardness-dependent, all acute and chronic values in Tables B3 and B4 have been adjusted to a hardness of 50 mg/L.

Criterion Maximum Concentration (CMC)

The SMAVs given in Table B3 for the green sunfish, bluegill, coho salmon, and rainbow trout were derived from U.S. EPA (1985) by giving preference to results of "FT,M" tests. Several SMAVs given in U.S. EPA (1985) were changed or eliminated due to deletion of tests that were conducted in river water by Spehar and Carlson (1984a,b).

The Final Acute Value (FAV) was calculated using the four lowest Genus Mean Acute Values in Table B3, resulting in an FAV of 4.134 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 2.067 ug/L, as total recoverable cadmium, at a hardness of 50 mg/L. The CMC was related to hardness using the slope of 1.128 that was derived in U.S. EPA (1985):

$$CMC = e^{1.128(\ln \text{hardness}) - 3.6867}$$

Criterion Continuous Concentration (CCC)

Two chronic values given in U.S. EPA (1985) were not used here because the tests were conducted in river water by Spehar and Carlson (1984a,b). The chronic value given in U.S. EPA (1985) for *Moina macrocopa* was not used here because the concentrations of cadmium were not measured.

Chronic toxicity tests have been conducted on cadmium with a wide variety of aquatic species and the resulting ACRs have a wide range, even within sensitive species (U.S. EPA 1985). Therefore, the Final Chronic Value (FCV) was calculated using the eight-family procedure that was used to calculate the FAV and was used to calculate the FCV for cadmium in U.S. EPA (1985). As in U.S.

EPA (1985), the FCV was calculated using the value of n used in the calculation of the FAV (i.e., n = 43). The FCV was 1.4286 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. Thus the CCC was 1.4286 ug/L, as total recoverable cadmium, at a hardness of 50 mg/L. The CCC was related to hardness using the slope of 0.7852 that was derived in U.S. EPA (1985):

$$CCC = e^{0.7852(\ln \text{hardness}) - 2.715}$$

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 cadmium does not exceed the numerical value (in ug/L) given by the equation

$$CCC = e^{0.7852(\ln \text{hardness}) - 2.715}$$

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

$$CMC = e^{1.128(\ln \text{hardness}) - 3.6867}$$

more than once every three years on the average.

Table B1. New Acute Values for Cadmium

Species	Method*	Hardness (mg/L as $CaCO_3$)	Acute Value (ug/L)	Adjusted Acute Value (ug/L)**	Reference
Cladoceran, Ceriodaphnia reticulata	S,U	240	184	31.36	Elnabarawy et al. 1986
Cladoceran, Daphnia pulex	S,U	120	70	26.07	Hall et al. 1986
Cladoceran, Daphnia pulex	S,U	200	50	10.47	Hall et al. 1986
Cladoceran, Daphnia pulex	S,U	200	100	20.94	Hall et al. 1986
Cladoceran, Daphnia pulex	S,U	240	319	54.37	Elnabarawy et al. 1986
Cladoceran, Daphnia magna	S,U	240	178	30.3	Elnabarawy et al. 1986
Amphipod, Crangonyx pseudogracilis	S,U	50	1700	1700	Martin and Holdich 1986
Crayfish, Orconectes virilis	S,U	26	6100	12755	Mirenda 1986
Rainbow trout, Oncorhynchus mykiss	FT,M	9.2	<0.5	<3.37	Cusimano and Brakke 1986
Rainbow trout, Oncorhynchus mykiss	FT,M	50	30	30	Van Leeuwen et al. 1985
Rainbow trout, Oncorhynchus mykiss	FT,M	50	10	10	Van Leeuwen et al. 1985
Rainbow trout (28-day egg), Oncorhynchus mykiss	FT,M	50	9200	9200***	Van Leeuwen et al. 1985
Rainbow trout (14-day egg), Oncorhynchus mykiss	FT,M	50	7500	7500***	Van Leeuwen et al. 1985
Rainbow trout (24-hr. egg), Oncorhynchus mykiss	FT,M	50	13000	13000***	Van Leeuwen et al. 1985
Rainbow trout (0-hr. egg), Oncorhynchus mykiss	FT,M	50	13000	13000***	Van Leeuwen et al. 1985

Table B1. (Cont.)

Species	Method*	Hardness (mg/L as $CaCO_3$)	Acute Value (ug/L)	Adjusted Acute Value (ug/L)**	Reference
Striped bass, *Morone saxatilis*	S,U	40	4	5.14	Palawski et al. 1985
Striped bass, *Morone saxatilis*	S,U	285	10	1.4	Palawski et al. 1985

* FT = flow-through, M = measured, S = static, U = unmeasured.
** Adjusted to a hardness of 50 mg/L using a slope of 1.128.
*** Not used in the calculation of the SMAV because data were available for a more sensitive life stage.

Table B2. New Chronic Values for Cadmium

Species	Test*	Hardness (mg/L as $CaCO_3$)	Chronic Value (ug/L)	Adjusted Chronic Value (ug/L)**	Reference
Cladoceran, Ceriodaphnia reticulata	LC	240	0.4	0.12***	Elnabarawy et al. 1986
Cladoceran, Daphnia magna	LC	240	4.3	1.25***	Elnabarawy et al. 1986
Cladoceran, Daphnia pulex	LC	106	7.07	3.919	Ingersoll and Winner 1982
Cladoceran, Daphnia pulex	LC	65	7.49	6.096	Niederlehner 1984
Cladoceran, Daphnia pulex	LC	240	13.7	4***	Elnabarawy et al. 1986
Oligochaete, Aeolosoma headleyi	LC	65	25.19	20.50	Niederlehner 1984

* LC = life cycle.
** Adjusted to a hardness of 50 mg/L using a slope of 0.7852.
*** Not used in derivation of the criterion because the concentrations of cadmium were not measured.

Table B3. Ranked Genus Mean Acute Values for Cadmium

Rank*	Genus Mean Acute Value (ug/L)**	Species	Species Mean Acute Value (ug/L)**
43	12755	Crayfish, Orconectes virilis	12755
42	8325	Goldfish, Carassius auratus	8325
41	8100	Damselfly, (Unidentified)	8100
40	7921	Tubificid worm, Rhyacodrilus montana	7921
39	7685	Mosquitofish, Gambusia affinis	7685
38	6915	Tubificid worm, Stylodrilus heringianus	6915
37	4990	Tubificid worm, Spirosperma ferox	4401
		Tubificid worm, Spirosperma nikolskyi	5658
36	4977	Threespine stickleback Gasterosteus aculeatus	4977
35	4778	Tubificid worm, Varichaeta pacifica	4778
34	4024	Tubificid worm, Tubifex tubifex	4024
33	4024	Tubificid worm, Quistradilus multisetosus	4024
32	3800	Snail, Amnicola sp.	3800
31	3570	Guppy, Poecilia reticulata	3570
30	3514	White sucker, Catostomus commersoni	3514
29	3400	Caddisfly, (Unidentified)	3400
28	3018	Tubificid worm, Branchiura sowerbyi	3018

Table B3. (Cont.)

Rank*	Genus Mean Acute Value (ug/L)**	Species	Species Mean Acute Value (ug/L)**
27	2888	Flagfish, *Jordanella floridae*	2888
26	2400	Northern squawfish, *Ptychocheilus oregonensis*	2400
25	2395	Green sunfish, *Lepomis cyanellus*	2399
		Pumpkinseed, *Lepomis gibbosus*	1347
		Bluegill, *Lepomis macrochirus*	4249
24	2310	Mayfly, *Ephemerella grandis*	2310
23	2137	Tubificid worm, *Limnodrilus hoffmeisteri*	2137
22	1700	Worm, *Nais sp.*	1700
21	1700	Amphipod, *Crangonyx pseudogracilis*	1700
20	1200	Midge, *Chironomus sp.*	1200
19	736	American eel, *Anguilla rostrata*	736
18	401	Isopod, *Asellus bicrenata*	401
17	221.9	Bryozoan, *Plumatella emarginata*	221.9
16	215.5	Common carp, *Cyprinus carpio*	215.5
15	156.9	Snail, *Physa gyrina*	156.9
14	142.5	Bryozoan, *Pectinatella magnifica*	142.5
13	104.0	Snail, *Aplexa hypnorum*	104.0

Table B3. (Cont.)

Rank*	Genus Mean Acute Value (ug/L)**	Species	Species Mean Acute Value (ug/L)**
12	98.79	Banded killifish, Fundulus diaphanus	98.79
11	74.99	Amphipod, Gammarus pseudolimnaeus	80.33
		Amphipod, Gammarus sp.	70.00
10	48.28	Cladoceran, Ceriodaphnia reticulata	48.28
9	42.8	Isopod, Lirceus alabamae	42.8
8	40.78	Cladoceran, Moina macrocopa	40.78
7	30.54	Bryozoan, Lophopodella carteri	30.54
6	30.50	Fathead minnow, Pimephales promelas	30.50
5	29.96	Cladoceran, Simocephalus serrulatus	33.2
		Cladoceran, Simocephalus vetulus	27.03
4	21.13	Cladoceran, Daphnia magna	14.2
		Cladoceran, Daphnia pulex	31.43
3	5.421	Coho salmon, Oncorhynchus kisutch	6.48
		Chinook salmon, Oncorhynchus tshawytscha	4.254
		Rainbow trout, Oncorhynchus mykiss	5.78
2	2.682***	White perch, Morone americana	7544
		Striped bass, Morone saxatilis	2.682****

Table B3. (Cont.)

Rank*	Genus Mean Acute Value (ug/L)**	Species	Species Mean Acute Value (ug/L)**
1	1.647	Brown trout, Salmo trutta	1.647

* Ranked from most resistant to most sensitive based on Genus Mean Acute Value.

** At hardness = 50 mg/L.

*** The 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 Palawski 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 = 4.134 ug/L

CMC = FAV/2 = 2.067 ug/L

As a function of hardness:

$$CMC = e^{1.128(\ln hardness) - 3.6867}$$

Table B4. Ranked Genus Mean Chronic Values for Cadmium

Rank*	Genus Mean Chronic Value (ug/L)**	Species	Species Mean Chronic Value (ug/L)**
12	20.50	Oligochaete, Aeolosoma headleyi	20.50
11	16.32	Bluegill, Lepomis macrochirus	16.32
10	15.40	Fathead minnow, Pimephales promelas	15.40
9	8.170	Smallmouth bass, Micropterus dolomieu	8.170
8	8.138	Northern pike, Esox lucius	8.138
7	7.849	White sucker, Catostomus commersoni	7.849
6	7.771	Atlantic salmon, Salmo salar	8.192
		Brown trout, Salmo trutta	7.372
5	5.336	Flagfish, Jordanella floridae	5.336
4	4.841	Snail, Aplexa hypnorum	4.841
3	4.383	Brook trout, Salvelinus fontinalis	2.362
		Lake trout, Salvelinus namaycush	8.134
2	3.399	Coho salmon, Oncorhynchus kisutch	4.289
		Chinook salmon, Oncorhynchus tshawytscha	2.694
1	0.1354***	Cladoceran, Daphnia magna	0.1354
		Cladoceran, Daphnia pulex	4.888

* Ranked from most resistant to most sensitive based on Genus Mean Chronic Value.

** At hardness = 50 mg/L.

*** The GMCV was set equal to the lower SMCV due to the large range in the SMCVs for this genus.

At hardness = 50 mg/L:

FCV = 1.4286 ug/L = CCC (calculated using n = 43)

As a function of hardness:

$$CCC = e^{0.7852(\ln \text{hardness}) - 2.715}$$

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1995 UPDATE:
Freshwater Aquatic Life Criterion for Chromium(III)

The new acceptable acute data for chromium(III) are given in Table C1; no new acceptable chronic data were found. These data were used with those given in Tables 1 and 2 of the criteria document for chromium (U.S. EPA 1984) to obtain the values given in Table C2. Because the toxicity of chromium(III) is hardness-dependent, all acute values in Table C2 have been adjusted to a hardness of 50 mg/L.

Criterion Maximum Concentration (CMC)

The Final Acute Value (FAV) was calculated using the four lowest Genus Mean Acute Values in Table C2, resulting in an FAV of 2044 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 1022 ug/L, as total recoverable chromium(III), at a hardness of 50 mg/L. The CMC was related to hardness using the slope of 0.819 that was derived in U.S. EPA (1985):

$$CMC = e^{0.819(\ln \text{hardness}) + 3.7256}$$

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). SMACRs were available for three species (Table C2) and the highest SMACR was obtained with the most resistant of the three. The other two SMACRs were within a factor of 2.4. The FACR was calculated as the geometric mean of the two ACRs and was 41.84. The FCV = FAV/FACR = (2044 ug/L)/(41.84) = 48.85 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. Thus the CCC was 48.85 ug/L, as total recoverable chromium(III), at a hardness of 50 mg/L. The CCC, was related to hardness using the slope of 0.819:

$$CCC = e^{0.819(\ln \text{hardness}) + 0.6848}$$

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 chromium(III) does not exceed the numerical value (in ug/L) given by the equation

$$CCC = e^{0.819(\ln \text{hardness}) + 0.6848}$$

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

$$CMC = e^{0.819(\ln \text{hardness}) + 3.7256}$$

more than once every three years on the average.

Table C1. New Acute Values for Chromium(III)

Species	Method*	Hardness (mg/L as $CaCO_3$)	Acute Value (ug/L)	Adjusted Acute Value (ug/L)**	Reference
Amphipod, *Crangonyx pseudogracilis*	S,U	50	291,000	291,000	Martin and Holdich 1986

* S = static, U = unmeasured.
** Adjusted to a hardness of 50 mg/L using a slope of 0.819.

Table C2. Ranked Genus Mean Acute Values for Chromium(III)

Rank*	Genus Mean Acute Value (ug/L)**	Species	Species Mean Acute Value (ug/L)**	Species Mean Acute-Chronic Ratio
19	291,000	Amphipod, Crangonyx pseudogracilis	291,000	-----
18	71060	Caddisfly, Hydropsyche betteni	71060	-----
17	50000	Caddisfly, Unidentified sp.	50000	-----
16	43100	Damselfly, Unidentified sp.	43100	-----
15	16010	Cladoceran, Daphnia magna	16010	>356.4***
14	15630	Banded killifish, Fundulus diaphanus	15630	-----
13	15370	Pumpkinseed, Lepomis gibbosus	15720	-----
		Bluegill, Lepomis macrochirus	15020	-----
12	14770	White perch, Morone americana	13320	-----
		Striped bass, Morone saxatilis	16370	-----
11	13230	Common carp, Cyprinus carpio	13230	-----
10	12860	American eel, Anguilla rostrata	12860	-----
9	11000	Midge, Chironomus sp.	11000	-----
8	10320	Fathead minnow, Pimephales promelas	10320	27.30
7	10210	Snail, Amnicola sp.	10210	-----
6	9669	Rainbow trout, Oncorhynchus mykiss	9669	64.11
5	9300	Worm, Nais sp.	9300	-----

Table C2. (Cont.)

Rank*	Genus Mean Acute Value (ug/L)**	Species	Species Mean Acute Value (ug/L)**	Species Mean Acute-Chronic Ratio
4	8684	Goldfish, Carassius auratus	8684	-----
3	7053	Guppy, Poecilia reticulata	7053	-----
2	3200	Amphipod, Gammarus sp.	3200	-----
1	2221	Mayfly, Ephemerella subvaria	2221	-----

* Ranked from most resistant to most sensitive based on Genus Mean Acute Value.
** At hardness = 50 mg/L.
*** Not used in the calculation of the Final Acute-Chronic Ratio.

At hardness = 50 mg/L:

FAV = 2044 ug/L

CMC = FAV/2 = 1022 ug/L

As a function of hardness:

$$CMC = e^{0.819(\ln \text{hardness}) + 3.7256}$$

FACR = 41.84

At hardness = 50 mg/L:

FCV = FAV/FACR = (2044 mg/L)/(41.84) = 48.85 ug/L = CCC

As a function of hardness:

$$CCC = e^{0.819(\ln \text{hardness}) + 0.6848}$$

References

Martin, T.R., and D.M. Holdich. 1986. The Acute Lethal Toxicity of Heavy Metals to Peracarid Crustaceans (with Particular Reference to Fresh-water Asellids and Gammarids). Water Res. 20:1137-1147.

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1995 UPDATE:
Freshwater Aquatic Life Criterion for Chromium(VI)

The new acceptable acute data for chromium(VI) are given in Table D1; no new acceptable chronic data were used. These new data were used with those given in Tables 1 and 2 of the criteria document for chromium (U.S. EPA 1985) to obtain the values given in Table D2.

Criterion Maximum Concentration (CMC)

The Final Acute Value (FAV) was calculated using the four lowest Genus Mean Acute Values given in Table D2, resulting in a FAV of 32.04 ug/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 16.02 ug/L, as total recoverable chromium(VI).

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). Eight SMACRs were available (Table D2), but three were high SMACRs that were obtained with resistant species and one was a "greater than" value. Of the eight, only four were appropriate for use in calculating the FACR and the four were within a factor of 6. The FACR was calculated as the geometric mean of these four and was 2.917. The FCV = FAV/FACR = (32.04 ug/L)/(2.917) = 10.98 ug/L. This value did not need to be lowered to protect a commercially or recreationally important species. The CCC was 10.98 ug/L, as total recoverable chromium(VI).

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 chromium(VI) does not exceed 10.98 ug/L more than once every three years on the average and if the one-hour average concentration does not exceed 16.02 ug/L more than once every three years on the average.

Table D1. New Acute Values for Chromium(VI)

Species	Method*	Chemical	Acute Value (ug/L)	Reference
Cladoceran, Daphnia magna	S,U	K-dichromate	900**	Berglind and Dave 1984
Cladoceran, Daphnia magna	S,U	Na-dichromate	112**	Elnabarawy et al. 1986
Cladoceran, Daphnia pulex	S,M	K-dichromate	170**	Dorn et al. 1987
Cladoceran, Daphnia pulex	S,U	K-dichromate	190**	Dorn, et al. 1987
Cladoceran, Daphnia pulex	S,M	K-dichromate	20**	Dorn, et al. 1987
Cladoceran, Daphnia pulex	S,U	K-dichromate	20**	Dorn, et al. 1987
Cladoceran, Daphnia pulex	S,M	K-dichromate	40**	Dorn, et al. 1987
Cladoceran, Daphnia pulex	S,U	K-dichromate	40**	Dorn, et al. 1987
Cladoceran, Daphnia pulex	S,U	Na-dichromate	122**	Elnabarawy et al. 1986
Cladoceran, Daphnia pulex	S,M	K-dichromate	180**	Jop et al. 1987
Cladoceran, Daphnia pulex	S,M	K-dichromate	180**	Jop et al. 1987
Amphipod, Crangonyx pseudogracilis	R,U	K-dichromate	420	Martin and Holdich 1986
Amphipod, Crangonyx pseudogracilis	R,U	K-dichromate	810	Martin and Holdich 1986
Bluegill, Lepomis macrochirus	S,M	K-dichromate	182,000**	Jop et al. 1987
Bluegill, Lepomis macrochirus	S,M	K-dichromate	154,000**	Jop et al. 1987
Bluegill, Lepomis macrochirus	S,M	K-dichromate	201,240**	Dorn et al. 1987

Table D1. (Cont.)

Species	Method*	Chemical	Acute Value (ug/L)	Reference
Bluegill, Lepomis macrochirus	S,U	K-dichromate	164,730**	Dorn et al. 1987
Bluegill, Lepomis macrochirus	S,M	K-dichromate	199,200**	Dorn et al. 1987
Bluegill, Lepomis macrochirus	S,U	K-dichromate	158,360**	Dorn et al. 1987
Bluegill, Lepomis macrochirus	S,M	K-dichromate	148,310**	Dorn et al. 1987
Bluegill, Lepomis macrochirus	S,U	K-dichromate	146,530**	Dorn et al. 1987
Fathead minnow, Pimephales promelas	S,M	K-dichromate	46,000**	Jop et al. 1987
Fathead minnow, Pimephales promelas	S,M	K-dichromate	34,000**	Jop et al. 1987
Fathead minnow, Pimephales promelas	S,U	K-dichromate	26,130**	Dorn et al. 1987
Fathead minnow, Pimephales promelas	S,M	K-dichromate	26,410**	Dorn et al. 1987

* S = static, FT = flow-through, M = measured, U = unmeasured.
** Not used in the calculation of the SMAV because data were available for this species from a "FT,M" test.

Table D2. Ranked Genus Mean Acute Values for Chromium(VI)

Rank*	Genus Mean Acute Value (ug/L)	Species	Species Mean Acute Value (ug/L)	Species Mean Acute-Chronic Ratio
28	1,870,000	Stonefly, Neophasganophora capitata	1,870,000	-----
27	176,000	Crayfish, Orconectes rusticus	176,000	-----
26	140,000	Damselfly, Enallagma aspersum	140,000	-----
25	123,500	Green sunfish, Lepomis cyanellus	114,700	-----
		Bluegill, Lepomis macrochirus	132,900	-----
24	119,500	Goldfish, Carassius auratus	119,500	-----
23	72,600	White crappie, Pomoxis annularis	72,600	-----
22	69,000	Rainbow trout, Oncorhynchus mykiss	69,000	260.8**
21	67,610	Emerald shiner, Notropis atherinoides	48,400	-----
		Striped shiner, Notropis chrysocephalus	85,600	-----
		Sand shiner, Notropis stramineus	74,600	-----
20	61,000	Midge, Chironomus tentans	61,000	-----
19	59,000	Brook trout, Salvelinus fontinalis	59,000	223**
18	57,300	Midge, Tanytarsus dissimilis	57,300	-----
17	51,250	Central stoneroller, Campostoma anomalum	51,250	-----
16	49,600	Silverjaw minnow, Ericymba buccata	49,600	-----

Table D2. (Cont.)

Rank*	Genus Mean Acute Value (ug/L)	Species	Species Mean Acute Value (ug/L)	Species Mean Acute-Chronic Ratio
15	47,180	Bluntnose minnow, *Pimephales notatus*	54,225	-----
		Fathead minnow, *Pimephales promelas*	41,050	18.55**
14	46,000	Johnny darter, *Etheostoma nigrum*	46,000	-----
13	36,300	Yellow perch, *Perca flavescens*	36,300	-----
12	30,450	Striped bass, *Morone saxatilis*	30,450	-----
11	30,000	Guppy, *Poecilia reticulata*	30,000	-----
10	23,010	Snail, *Physa heterostropha*	23,010	-----
9	1,560	Bryozoan, *Lophopodella carteri*	1,560	-----
8	1,440	Bryozoan, *Pectinatella magnifica*	1,440	-----
7	650	Bryozoan, *Plumatella emarginata*	650	-----
6	630	Amphipod, *Hyalella azteca*	630	-----
5	583	Amphipod, *Crangonyx pseudogracilis*	583	-----
4	67.1	Amphipod, *Gammarus pseudolimnaeus*	67.1	-----
3	45.1	Cladoceran, *Ceriodaphnia reticulata*	45.1	1.13
2	36.35	Cladoceran, *Simocephalus serrulatus*	40.9	2.055
		Cladoceran, *Simocephalus vetulus*	32.3	5.267

Table D2. (Cont.)

Rank*	Genus Mean Acute Value (ug/L)	Species	Species Mean Acute Value (ug/L)	Species Mean Acute-Chronic Ratio
1	28.94	Cladoceran, Daphnia magna	23.07	>6.957**
		Cladoceran, Daphnia pulex	36.3	5.92

* Ranked from most resistant to most sensitive based on Genus Mean Acute Value.

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

FAV = 32.04 ug/L

CMC = FAV/2 = 16.02 ug/L

FACR = 2.917

FCV = FAV/FACR = (32.04 ug/L)/(2.917) = 10.98 ug/L = CCC

References

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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):

$$CMC = e^{0.9422(\ln \text{hardness}) - 1.700}$$

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 of 50 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):

$$CCC = e^{0.8545(\ln \text{hardness}) - 1.702}$$

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

$$CCC = e^{0.8545(\ln \text{hardness}) - 1.702}$$

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

$$CMC = e^{0.9422(\ln \text{hardness}) - 1.700}$$

more than once every three years on the average.

Table E1. New Acute Values for Copper

Species	Method*	Hardness (mg/L as $CaCO_3$)	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	17	>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.

Table E2. New Chronic Values for Copper

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

* ELS = early life stage.

Table E3. Ranked Genus Mean Acute Values for Copper

Rank*	Genus Mean Acute Value (ug/L)**	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	Banded killifish, Fundulus diaphanus	790.6	-----
31	684.3	Mozambique tilapia Tilapia mossambica	684.3	-----
30	331.8	Striped shiner, Notropis chrysocephalus	331.8	-----
29	289	Goldfish, Carassius auratus	289	-----
28	242.7	Worm, Lumbriculus variegatus	242.7	-----

Table E3. (Cont.)

Rank*	Genus Mean Acute Value (ug/L)**	Species	Species Mean Acute Value (ug/L)**	Species Mean Acute-Chronic Ratio
27	196.1	Mosquitofish, Gambusia affinis	196.1	-----
26	170.2~	Midge, Chironomus tentans	197	-----
		Midge, Chironomus decorus	834	-----
		Midge, Chironomus sp.	30	-----
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	-----
		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	-----

Table E3. (Cont.)

Rank*	Genus Mean Acute Value (ug/L)**	Species	Species Mean Acute Value (ug/L)**	Species Mean Acute-Chronic Ratio
15	83.97	Creek chub, Semotilus atromaculatus	83.97	-----
14	83	Guppy, Poecilia reticulata	83	-----
13	78.55	Central stoneroller, Campostoma anomalum	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 Value (ug/L)**	Species	Species Mean Acute Value (ug/L)**	Species Mean Acute-Chronic Ratio
4	22.09	Amphipod, *Gammarus pseudolimnaeus*	22.09	3.297
3	16.74	Northern squawfish, *Ptychocheilus oregonensis*	16.74	-----
2	14.48	Cladoceran, *Daphnia magna*	19.88	2.418
		Cladoceran, *Daphnia pulex*	16.5	-----
		Cladoceran, *Daphnia pulicaria*	9.263	-----
1	9.92	Cladoceran, *Ceriodaphnia reticulata*	9.92	-----

* Ranked from most resistant to most sensitive based on Genus Mean Acute Value.

** 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:

$$CMC = e^{0.9422(\ln \text{hardness}) - 1.700}$$

FACR = 2.823

At hardness = 50 mg/L:
~~~

$$FCV = FAV/FACR = (14.57\ ug/L)/(2.823) = 5.161\ ug/L = CCC$$

As a function of hardness:

$$CCC = e^{0.8545(\ln hardness) - 1.702}$$

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1995 UPDATE:
Freshwater Aquatic Life Criterion for Cyanide

No new acceptable acute or chronic data were found for cyanide. Therefore, the data in the existing criteria document for cyanide (U.S. EPA 1985) were used as the basis for the derivation of this criterion. The new taxonomy for salmonids was used (Table F1), but this did not cause a change in the criterion for cyanide.

Criterion Maximum Concentration (CMC)

The Final Acute Value (FAV) was calculated using the four lowest Genus Mean Acute Values given in Table F1, resulting in a FAV of 45.77 ug/L. Because the SMAV of the commercially and recreationally important rainbow trout was 44.73 ug/L, the FAV was lowered to 44.73 ug/L. The CMC was calculated by dividing the FAV by 2, resulting in a CMC of 22.36 ug free cyanide (as CN)/L.

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). Five SMACRs are available (Table F1), but one was a high SMACR that was obtained with a resistant species; the other four were within a factor of 1.5. The FACR was calculated as the geometric mean of these four and was 8.568. The FCV = FAV/FACR = (44.73 ug/L)/(8.568) = 5.221 ug/L. This value does not need to be lowered to protect a commercially or recreationally important species. The CCC was 5.221 ug free cyanide (as CN)/L.

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 free cyanide (as CN) does not exceed 5.221 ug/L more than once every three years on the average and if the one-hour average concentration does not exceed 22.36 ug/L more than once every three years on the average.

Table F1. Ranked Genus Mean Acute Values for Cyanide

Rank*	Genus Mean Acute Value (ug/L)	Species	Species Mean Acute Value (ug/L)	Species Mean Acute-Chronic Ratio
16	2490	Midge, Tanytarsus dissimilis	2490	-----
15	2326	Isopod, Asellus communis	2326	68.29**
14	432	Snail, Physa heterostropha	432	-----
13	426	Stonefly, Pteronarcys dorsata	426	-----
12	318	Goldfish, Carassius auratus	318	-----
11	167	Amphipod, Gammarus pseudolimnaeus	167	9.111
10	147	Guppy, Poecilia reticulata	147	-----
9	125.1	Fathead minnow, Pimephales promelas	125.1	7.633
8	123.6	Cladoceran, Daphnia magna	160	-----
		Cladoceran, Daphnia pulex	95.55	-----
7	102	Largemouth bass, Micropterus salmoides	102	-----
6	102	Black crappie, Pomoxis nigromaculatus	102	-----
5	99.28	Bluegill, Lepomis macrochirus	99.28	7.316
4	92.64	Yellow perch, Perca flavescens	92.64	-----
3	90.00	Atlantic salmon, Salmo salar	90.00	-----
2	85.80	Brook trout, Salvelinus fontinalis	85.80	10.59
1	44.73	Rainbow trout Oncorhynchus mykiss	44.73	-----

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* Ranked from most resistant to most sensitive based on Genus Mean Acute Value.

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

Calculated FAV = 45.77 ug/L

Lowered to protect rainbow trout:

FAV = 44.73 ug/L

CMC = FAV/2 = 22.36 ug/L

FACR = 8.568

FCV = FAV/FACR = (44.73 ug/L)/(8.568) = 5.221 ug/L = CCC

References

U.S. EPA. 1985. Ambient Water Quality Criteria for Cyanide - 1984. EPA 440/5-84-028. National Technical Information Service, Springfield, VA.

1995 UPDATE:
Freshwater Aquatic Life Criterion for Dieldrin

The new acceptable acute data for dieldrin are given in Table G1; no new acceptable chronic data were found. These new data were used with those given in Tables 1 and 2 of the criteria document for dieldrin (U.S. EPA 1980) to obtain the values given in Table G2. Although results from the following publications were used in U.S. EPA (1980), they were not considered acceptable for use here: Santharam et al. (1976), Gaufin (1965), and Jensen and Gaufin (1964).

Criterion Maximum Concentration (CMC)

The Final Acute Value (FAV) was calculated using the four lowest Genus Mean Acute Values given in Table G2, resulting in a FAV of 0.4749 ug/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 0.2374 ug/L.

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). Two SMACRs were given in Table G2; a third SMACR of 6.2 was given in U.S. EPA (1980) for the saltwater mysid. These three were within a factor of 1.8. The FACR was calculated as the geometric mean of the three SMACRs and was 8.530. The FCV = FAV/FACR = (0.4749 ug/L)/(8.530) = 0.0557 ug/L. This value did not need to be lowered to protect a commercially or recreationally important species. The CCC was 0.0557 ug/L.

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 dieldrin does not exceed 0.0557 ug/L more than once every three years on the average and if the one-hour average concentration does not exceed 0.2374 ug/L more than once every three years on the average.

Table G1. New Acute Values for Dieldrin

Species	Method*	Test Duration (hrs)	Acute Value (ug/L)	Reference
Cladoceran, Daphnia pulex	S,M	48	251	Daniels and Allan 1981
Cladoceran, Daphnia pulex	S,U	48	190	Mayer and Ellersieck 1986
Stonefly, Claassenia sabulosa	S,U	96	0.6	Mayer and Ellersieck 1986
Stonefly, Pteronarcys californica	S,U	96	0.5	Mayer and Ellersieck 1986
Stonefly, Pteronarcella badia	S,U	96	0.5	Mayer and Ellersieck 1986
Damselfly, Ischnura verticalis	S,U	96	12	Mayer and Ellersieck 1986
Annelid, Lumbriculus variegatus	FT,M	96	21.8	Brooke 1993
Rainbow trout, Oncorhynchus mykiss	S,U	96	1.2**	Mayer and Ellersieck 1986
Rainbow trout, Oncorhynchus mykiss	FT,M	96	0.62	Shubat and Curtis 1986
Rainbow trout, Oncorhynchus mykiss	S,U	96	3**	Van Leeuwen et al. 1985
Goldfish, Carassius auratus	S,U	96	1.8	Mayer and Ellersieck 1986
Fathead minnow, Pimephales promelas	S,U	96	3.8	Mayer and Ellersieck 1986
Bluegill, Lepomis macrochirus	S,U	96	3.1	Mayer and Ellersieck 1986
Bluegill, Lepomis macrochirus	S,U	96	7	Sanders 1972
Pumpkinseed, Lepomis gibbosus	S,U	96	6.7	Cairns and Scheier 1964
Cutthroat trout, Oncorhynchus clarki	S,U	96	6	Mayer and Ellersieck 1986

Table G1. (Cont.)

Species	Method*	Test Duration (hrs)	Acute Value (ug/L)	Reference
Channel catfish, Ictalurus punctatus	S,U	96	4.5	Mayer and Ellersieck 1986
Largemouth bass, Micropterus salmoides	S,U	96	3.5	Mayer and Ellersieck 1986

* S = static, FT = flow-through, U = unmeasured, M = measured.
** Not used in the calculation of the SMAV because data were available for this species from a "FT,M" test.

Table G2. Ranked Genus Mean Acute Values for Dieldrin

Rank*	Genus Mean Acute Value (ug/L)	Species	Species Mean Acute Value (ug/L)	Species Mean Acute-Chronic Ratio
18	740	Crayfish, Orconectes nais	740	-----
17	534	Amphipod, Gammarus lacustris	460	-----
		Amphipod, Gammarus fasciatus	620	-----
16	228	Cladoceran, Daphnia pulex	228	-----
15	214	Cladoceran, Simocephalus serrulatus	214	-----
14	21.8	Annelid, Lumbriculus variegatus	21.8	-----
13	20	Glass shrimp Palaemonetes kadiakensis	20	-----
12	17.7	Fathead minnow, Pimephales promelas	17.7	-----
11	12	Damselfly, Ischnura verticalis	12	-----
10	8.6	Goldfish, Carassius auratus	8.6	-----
9	8.5	Pumpkinseed, Lepomis gibbosus	6.7	-----
		Bluegill, Lepomis macrochirus	11.5	-----
		Green sunfish, Lepomis cyanellus	8.1	-----
8	5	Isopod, Asellus brevicaudus	5	-----
7	4.5	Channel catfish, Ictalurus punctatus	4.5	-----
6	4.5	Guppy, Poecilia reticulata	4.5	9.1

Table G2. (Cont.)

Rank*	Genus Mean Acute Value (ug/L)	Species	Species Mean Acute Value (ug/L)	Species Mean Acute-Chronic Ratio
5	3.5	Largemouth bass, Micropterus salmoides	3.5	-----
4	0.62**	Chinook salmon, Oncorhynchus tshawytscha	6.1	-----
		Coho salmon, Oncorhynchus kisutch	10.8	-----
		Cutthroat trout, Oncorhynchus clarki	6	-----
		Rainbow trout, Oncorhynchus mykiss	0.62	11
3	0.6	Stonefly, Claassenia sabulosa	0.6	-----
2	0.5	Stonefly, Pteronarcys californica	0.5	-----
1	0.5	Stonefly, Pteronarcella badia	0.5	-----

* Ranked from most resistant to most sensitive based on Genus Mean Acute Value.
** The GMAV was set equal to the lowest SMAV due to the large range in the SMAVs in this genus.

FAV = 0.4749 ug/L

CMC = FAV/2 = 0.2374 ug/L

FACR = 8.530

FCV = FAV/FACR = (0.4749 ug/L)/(8.530) = 0.0557 ug/L = CCC

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1995 UPDATE:
Freshwater Aquatic Life Criterion for Endrin

The new acceptable acute data for endrin are given in Table H1; no new acceptable chronic data were found. These new data were used with those given in Tables 1 and 2 of the criteria document for endrin (U.S. EPA 1980) to obtain the values given in Table H2. Results in the following publications were used in U.S. EPA (1980) but were not considered acceptable for use here: Katz and Chadwick (1961), Naqui and Ferguson (1968), Nebeker and Gaufin (1964), Gaufin et al. (1965), Jensen and Gaufin (1966), Post and Schroeder (1971), Mount (1962), and Solon (1969).

Criterion Maximum Concentration (CMC)

The Final Acute Value (FAV) was calculated using the four lowest Genus Mean Acute Values given in Table H2, resulting in a FAV of 0.1728 ug/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 0.0864 ug/L.

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). Four ACRs were given in U.S. EPA (1980) but the ACR for the fathead minnow was considered unacceptable for use here. ACRs of 1.9 and 18 were determined with saltwater species, whereas an ACR of 3.3 was obtained with a freshwater species (Table H2); the three were within a factor of 9.5. The FACR was calculated as the geometric mean of the other three and was 4.833. The FCV = FAV/FACR = (0.1728 ug/L)/(4.833) = 0.03575 ug/L. This value did not need to be lowered to protect a commercially or recreationally important species. The CCC was 0.03575 ug/L.

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 endrin does not exceed 0.03575 ug/L more than once every three years on the average and if the one-hour average concentration does not exceed 0.0864 ug/L more than once every three years on the average.

Table H1. New Acute Values for Endrin

Species	Method*	Test Duration (hrs)	Acute Value (ug/L)	Reference
Cladoceran, Ceriodaphnia reticulata	S,U	48	24	Elnabarawy et al. 1986
Cladoceran, Daphnia magna	S,U	48	4.2	Mayer and Ellersieck 1985
Cladoceran, Daphnia magna	S,U	48	59	Elnabarawy et al. 1986
Cladoceran, Daphnia magna	S,U	48	41	Mayer and Ellersieck 1985
Cladoceran, Daphnia magna	S,U	48	74	Mayer and Ellersieck 1985
Cladoceran, Daphnia magna	S,M	48	160	Thurston et al. 1985
Cladoceran, Daphnia pulex	S,U	48	20	Mayer and Ellersieck 1985
Cladoceran, Daphnia pulex	S,U	48	30	Elnabarawy et al. 1986
Annelid, Lumbriculus variegatus	FT,M	96	42.6	Brooke 1993
Snipe fly, Atherix variegatus	S,U	96	4.6	Mayer and Ellersieck 1985
Midge, Tanytarsus dissimilis	S,M	48	0.84	Thurston et al. 1985
Stonefly, Acroneuria pacifica	S,U	96	> 0.18**	Mayer and Ellersieck 1985
Crayfish, Orconectes immunis	FT,M	96	89	Thurston et al. 1985
Damselfly, Ischnura verticalis	S,U	96	2.4	Mayer and Ellersieck 1986
Damselfly, Ischnura verticalis	S,U	96	2.1	Mayer and Ellersieck 1986
Yellow perch, Perca flavescens	FT,U	96	0.15	Mayer and Ellersieck 1986
Largemouth bass, Micropterus salmoides	S,U	96	0.31	Mayer and Ellersieck 1986

Table H1. (Cont.)

Species	Method*	Test Duration (hrs)	Acute Value (ug/L)	Reference
Black bullhead, Ictalurus melas	S,U	96	1.1	Mayer and Ellersieck 1986
Channel catfish, Ictalurus punctatus	S,U	96	0.32***	Mayer and Ellersieck 1986
Channel catfish, Ictalurus punctatus	S,U	96	1.1***	Mayer and Ellersieck 1986
Channel catfish, Ictalurus punctatus	FT,M	96	0.42	Thurston et al. 1985
Rainbow trout, Oncorhynchus mykiss	S,U	96	0.75***	Mayer and Ellersieck 1986
Rainbow trout, Oncorhynchus mykiss	FT,M	96	0.3	Thurston et al. 1985
Goldfish, Carassius auratus	FT,U	96	0.44***	Mayer and Ellersieck 1986
Goldfish, Carassius auratus	FT,M	96	0.95	Thurston et al. 1985
Fathead minnow, Pimephales promelas	S,U	96	1.8***	Mayer and Ellersieck 1986
Fathead minnow, Pimephales promelas	FT,M	96	0.65	Thurston et al. 1985
Mosquitofish, Gambusia affinis	S,U	96	1.1***	Mayer and Ellersieck 1986
Mosquitofish, Gambusia affinis	FT,M	96	0.69	Thurston et al. 1985
Carp, Cyprinus carpio	FT,U	96	0.32	Mayer and Ellersieck 1986
Bluegill, Lepomis macrochirus	FT,M	96	0.21	Thurston et al. 1985
Bullfrog tadpole, Rana catesbeiana	FT,M	96	2.5	Thurston et al. 1985

* FT = flow-through, S = static, U = unmeasured, M = measured.
** Not used in the calculation of the FAV because it is not appropriate to have one of the four lowest GMAVs be a "greater than" value.
*** Not used in the calculation of the SMAV because data were available for this species from a "FT,M" test.

Table H2. Ranked Genus Mean Acute Values for Endrin

Rank*	Genus Mean Acute Value (ug/L)	Species	Species Mean Acute Value (ug/L)	Species Mean Acute-Chronic Ratio
27	64	Mayfly, Hexagenia bilineata	64	-----
26	53	Crayfish, Orconectes nais	32	-----
		Crayfish, Orconectes immunis	89	-----
25	43	Annelid, Lumbriculus variegatus	43	-----
24	38	Cladoceran, Daphnia magna	59	-----
		Cladoceran, Daphnia pulex	24	-----
23	34	Cladoceran, Simocephalus serrulatus	34	-----
22	24	Cladoceran, Ceriodaphnia reticulata	24	-----
21	4.6	Snipe fly, Atherix variegatus	4.6	-----
20	3.0	Amphipod, Gammarus fasciatus	3.1	-----
		Amphipod, Gammarus lacustris	3.0	-----
19	2.5	Bullfrog tadpole Rana catesbeiana	2.5	-----
18	2.1	Damselfly, Ischnura verticalis	2.1	-----
17	1.6	Guppy, Poecilia reticulata	1.6	-----
16	1.5	Isopod, Asellus brevicaudus	1.5	-----
15	1.3	Glass shrimp, Palaemonetes kadiakensis	1.3	-----
14	0.95	Goldfish, Carassius auratus	0.95	-----

Table H2. (Cont.)

Rank*	Genus Mean Acute Value (ug/L)	Species	Species Mean Acute Value (ug/L)	Species Mean Acute-Chronic Ratio
13	0.85	Flagfish, *Jordanella floridae*	0.85	3.3
12	0.84	Midge, *Tanytarsus dissimilis*	0.84	-----
11	0.76	Stonefly, *Claassenia sabulosa*	0.76	-----
10	0.69	Mosquitofish, *Gambusia affinis*	0.69	-----
9	0.68	Black bullhead, *Ictalurus melas*	1.1	-----
		Channel catfish, *Ictalurus punctatus*	0.42	-----
8	0.57	Coho salmon, *Oncorhynchus kisutch*	0.51	-----
		Chinook salmon, *Oncorhynchus tshawytscha*	1.2	-----
		Rainbow trout, *Oncorhynchus mykiss*	0.3	-----
7	0.54	Stonefly, *Pteronarcella badia*	0.54	-----
6	0.49	Fathead minnow, *Pimephales promelas*	0.49	-----
5	0.32	Common carp, *Cyprinus carpio*	0.32	-----
4	0.31	Largemouth bass, *Micropterus salmoides*	0.31	-----
3	0.25	Stonefly, *Pteronarcys californica*	0.25	-----
2	0.21	Bluegill, *Lepomis macrochirus*	0.21	-----
1	0.15	Yellow perch, *Perca flavescens*	0.15	-----

* Ranked from most resistant to most sensitive based on Genus Mean Acute Value.

FAV = 0.1728 ug/L

CMC = FAV/2 = 0.0864 ug/L

FACR = 4.833

FCV = FAV/FACR = (0.1728 ug/L)/(4.833) = 0.03575 ug/L = CCC

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1995 UPDATE:
Freshwater Aquatic Life Criterion for Lindane

The new acceptable acute data for lindane are given in Table I1; no new acceptable chronic data were found. These new data were used with those given in Tables 1 and 2 of the criteria document for lindane (U.S. EPA 1980) to obtain the values given in Table I2.

Criterion Maximum Concentration (CMC)

The Final Acute Value (FAV) was calculated using the four lowest Genus Mean Acute Values given in Table I2, resulting in a FAV of 1.903 ug/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 0.9515 ug/L.

Criterion Continuous Concentration (CCC)

Three ACRs were given in U.S. EPA (1980) but the ACR for the fathead minnow was considered unacceptable for use here. No new ACRs were available and so a FCV could not be calculated using either the eight-family procedure or the FACR procedure. Therefore, a CCC could not be determined.

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 by acute toxicity if the one-hour average concentration of lindane does not exceed 0.9515 ug/L more than once every three years on the average.

Table I1. New Acute Values for Lindane

Species	Method*	Test Duration (hrs)	Acute Value (ug/L)	Reference
Cladoceran, Daphnia magna	S,U	48	516	Randall et al. 1979
Cladoceran, Daphnia magna	S,M	48	1000	Hermens et al. 1984
Amphipod, Gammarus lacustris	S,U	96	88	Mayer and Ellersieck 1986
Snail, Lymnaea stagnalis	S,U	96	3.3	Bluzat and Senge 1979
Stonefly, Pteronarcys californicus	S,U	96	4.5	Mayer and Ellersieck 1986
Stonefly, Pteronarcys californicus	S,U	96	1	Mayer and Ellersieck 1986
Damselfly, Lestes congener	S,U	96	20	Federle and Collins 1976
Backswimmer, Notonecta undulata	S,U	96	3	Federle and Collins 1976
Crawling water beetle, Peltodytes sp.	S,U	96	20	Federle and Collins 1976
Coho salmon, Oncorhynchus kisutch	S,U	96	23	Mayer and Ellersieck 1986
Lake trout, Salvelinus namaycush	S,U	96	32	Mayer and Ellersieck 1986
Lake trout, Salvelinus namaycush	S,U	96	24	Mayer and Ellersieck 1986
Brown trout, Salmo trutta	S,U	96	24	Mayer and Ellersieck 1986
Brown trout, Salmo trutta	S,U	96	25	Mayer and Ellersieck 1986
Brown trout, Salmo trutta	FT,U	96	22	Mayer and Ellersieck 1986
Rainbow trout, Oncorhynchus mykiss	FT,M	96	22	Tooby and Durbin 1975
Rainbow trout, Oncorhynchus mykiss	S,U	96	18**	Mayer and Ellersieck 1986

Table I1. (Cont).

Species	Method*	Test Duration (hrs)	Acute Value (ug/L)	Reference
Rainbow trout, Oncorhynchus mykiss	S,U	96	24**	Mayer and Ellersieck 1986
Rainbow trout, Oncorhynchus mykiss	S,U	96	31**	Mayer and Ellersieck 1986
Rainbow trout, Oncorhynchus mykiss	S,U	96	41**	Mayer and Ellersieck 1986
Rainbow trout, Oncorhynchus mykiss	FT,M	96	30	Tooby and Durbin 1975
Bluegill, Lepomis macrochirus	S,U	96	57	Randall et al. 1979
Bluegill, Lepomis macrochirus	S,U	96	56	Mayer and Ellersieck 1986
Green sunfish, Lepomis cyanellus	S,U	96	70	Mayer and Ellersieck, 1986
Green sunfish, Lepomis cyanellus	S,U	96	83	Mayer and Ellersieck 1986
Yellow perch, Perca flavescens	FT,U	96	23	Mayer and Ellersieck 1986
Fathead minnow, Pimephales promelas	FT,U	96	77	Mayer and Ellersieck 1986
Fathead minnow, Pimephales promelas	S,U	96	67	Mayer and Ellersieck 1986
Fathead minnow, Pimephales promelas	S,U	96	86	Mayer and Ellersieck 1986
Goldfish, Carassius auratus	S,U	96	90	Macek and McAllister 1970
Goldfish, Carassius auratus	S,U	96	105	Mayer and Ellersieck 1986
Channel catfish, Ictalurus punctatus	S,U	96	49	Mayer and Ellersieck 1986
Fowlers toad, Bufo woodhousei fowleri	S,U	96	3200	Mayer and Ellersieck 1986
Western chorus frog, Pseudacris triseriata	S,U	96	2650	Mayer and Ellersieck 1986

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* S = static, FT = flow-through, U = unmeasured, M = measured.
** Not used in the calculation of the SMAV because data were available for this species from a "FT,M" test.

Table I2. Ranked Genus Mean Acute Values for Lindane

Rank*	Genus Mean Acute Value (ug/L)	Species	Species Mean Acute Value (ug/L)	Species Mean Acute-Chronic Ratio
23	3200	Fowlers toad, Bufo woodhousi fowleri	3200	-----
22	2650	Western chorus frog, Pseudacris triseriata	2650	-----
21	676	Cladoceran, Simocephalus serrulatus	676	-----
20	538	Cladoceran, Daphnia magna	630	33
		Cladoceran, Daphnia pulex	460	-----
19	207	Midge, Chironomus tentans	207	63
18	138	Guppy, Poecilia reticulata	138	-----
17	117	Goldfish, Carassius auratus	117	-----
16	90	Carp, Cyprinus carpio	90	-----
15	72	Fathead minnow, Pimephales promelas	72	-----
14	71	Bluegill, Lepomis macrochirus	56	-----
		Redear sunfish, Lepomis microlophus	83	-----
		Green sunfish, Lepomis cyanellus	76	-----
13	55	Channel catfish, Ictalurus punctatus	46	-----
		Black bullhead, Ictalurus melas	64	-----
12	40	Yellow perch, Perca flavescens	40	-----

Table I2. (Cont.)

Rank*	Genus Mean Acute Value (ug/L)	Species	Species Mean Acute Value (ug/L)	Species Mean Acute-Chronic Ratio
11	35	Brook trout, Salvelinus fontinalis	44	-----
		Lake trout, Salvelinus namaycush	28	-----
10	33	Rainbow trout, Oncorhynchus mykiss	26	-----
		Coho salmon, Oncorhynchus kisutch	36	-----
		Chinook salmon, Oncorhynchus tsawytscha	40	-----
9	32	Largemouth bass, Micropterus salmoides	32	-----
8	26.11	Amphipod, Gammarus fasciatus	10.49	-----
		Amphipod, Gammarus lacustris	65	-----
7	20	Damselfly, Lestes congener	20	-----
6	20	Crawling water beetle, Peltodytes sp.	20	-----
5	13	Brown trout, Salmo trutta	13	-----
4	10	Isopod, Asellus brevicaudus	10	-----
3	3.3	Snail, Lymnaea stagnalis	3.3	-----
2	3	Backswimmer, Notonecta undulata	3	-----
1	2.1	Stonefly, Pteronarcys californicus	2.1	-----

* Ranked from most resistant to most sensitive based on Genus Mean Acute Value.

FAV = 1.903 ug/L

CMC = FAV/2 = 0.9515 ug/L

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1995 UPDATE:
Freshwater Aquatic Life Criterion for Mercury(II)

The new acceptable acute data for mercury(II) are given in Table J1; no new chronic data were used. These new data were used with those given in Tables 1 and 2 of the criteria document for mercury(II) (U.S. EPA 1985) to obtain the values given in Table J2.

Criterion Maximum Concentration (CMC)

The Final Acute Value (FAV) was calculated using the four lowest Genus Mean Acute Values given in Table J2, resulting in a FAV of 3.388 ug/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 1.694 ug/L as total recoverable mercury(II).

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). ACRs were given for two freshwater species and one saltwater species in U.S. EPA (1985). The ACR obtained with the more resistant fathead minnow was much higher than the other two. The ACR obtained with the saltwater mysid was 3.095 and was similar to the Species Mean Acute-Chronic Ratio of 4.498 for *Daphnia magna*. The FACR was calculated as the geometric mean of the two SMACRs and was 3.731. The FCV = FAV/FACR = (3.388 ug/L)/(3.731) = 0.9081 ug/L. This value did not need to be lowered to protect a commercially or recreationally important species. The CCC was 0.9081 ug/L as total recoverable mercury(II).

The SMACR of >649.2 for the fathead minnow (Table J2) was not used in the calculation of the FACR because this species is acutely resistant to mercury(II). This SMACR is the geometric mean of >646.2, which was based on a life-cycle test, and >652.2, which was based on an early life-stage test. These two ACRs are so large that the two chronic values of <0.26 and <0.23 ug/L are both lower than the CCC of 0.9081 ug/L. Because the high SMACR was based on two tests with a fish and the two low SMACRs were obtained with invertebrates, it is quite possible that other fishes have SMACRs close to 649.2. The following estimated chronic values were obtained using Species Mean Acute Values from Table J2 and an estimated ACR of 649.2:

Species	Species Mean Acute Value	Estimated Chronic Value
Rainbow trout	275 ug/L	0.42 ug/L
Coho salmon	240 ug/L	0.37 ug/L
Bluegill	160 ug/L	0.25 ug/L

All three of these estimated chronic values are for important species and are more than a factor of two lower than the FCV of 0.9081 ug/L. In addition, the SMACR for the fathead minnow is greater than 649.2. Thus the CCC of 0.9081 ug/L might not adequately protect such important fishes as the rainbow trout, coho salmon, and bluegill.

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 mercury(II) does not exceed 0.9081 ug/L more than once every three years on the average and if the one-hour average concentration does not exceed 1.694 ug/L more than once every three years on the average. The concentration of 0.9081 ug/L might not adequately protect such important fishes as the rainbow trout, coho salmon, and bluegill.

Table J1. New Acute Values for Mercury(II)

Species	Method*	Acute Value (ug/L)	Reference
Cladoceran, Ceriodaphnia reticulata	S,U	2.9	Elnabarawy et al. 1986
Cladoceran, Daphnia magna,	S,U	9.6	Elnabarawy et al. 1986
Cladoceran, Daphnia pulex	S,U	3.8	Elnabarawy et al. 1986
Amphipod, Crangonyx pseudogracilis	S,U	1.0**	Martin and Holdich 1986
Midge, Chironomus riparius	S,M	750	Rossaro et al. 1986
Mosquitofish, Gambusia affinis	S,U	230	Paulose 1988
Walking catfish, Clarias batrachus	S,U	375	Kirubagaran and Joy 1988
Fathead minnow, Pimephales promelas	FT,M	172	Spehar and Fiandt 1986
Guppy, Poecilia reticulata	R,U	26	Khangarot and Ray 1987

* S = static, R = renewal, FT = flow-through, U = unmeasured, M = measured.

** Not used in the derivation of the criterion because the corresponding 48-hr LC50 is 470 ug/L, which is an unusually large decrease in the LC50 from 48 to 96 hours.

Table J2. Ranked Genus Mean Acute Values for Mercury(II)

Rank*	Genus Mean Acute Value (ug/L)	Species	Species Mean Acute Value (ug/L)	Species Mean Acute-Chronic Ratio
29	2000	Stonefly, Acroneuria lycorias	2000	-----
28	2000	Mayfly, Ephemerella subvaria	2000	-----
27	2000	Caddisfly, Hydropsyche betteni	2000	-----
26	1200	Caddisfly, (Unidentified)	1200	-----
25	1200	Damselfly, (Unidentified)	1200	-----
24	1000	Worm, Nais sp.	1000	-----
23	1000	Mozambique tilapia Tilapia mossambica	1000	-----
22	406.2	Tubificid worm, Spirosperma ferox	330	-----
		Tubificid worm, Spirosperma nikolskyi	500	-----
21	375	Walking catfish, Clarias batrachus	375	-----
20	370	Snail, Aplexa hypnorum	370	-----
19	257	Coho salmon, Oncorhynchus kisutch	240	-----
		Rainbow trout, Oncorhynchus mykiss	275	-----
18	250	Tubificid worm, Quistadrilus multisetosus	250	-----
17	240	Tubificid worm, Rhyacodrilus montana	240	-----
16	203	Mosquitofish, Gambusia affinis	203	-----
15	180	Tubificid worm, Limnodrilus hoffmeisteri	180	-----

Table J2. (Cont.)

Rank*	Genus Mean Acute Value (ug/L)	Species	Species Mean Acute Value (ug/L)	Species Mean Acute-Chronic Ratio
14	163	Fathead minnow, Pimephales promelas	163	> 649.2**
13	160	Bluegill, Lepomis macrochirus	160	-----
12	140	Tubificid worm, Tubifex tubifex	140	-----
11	140	Tubificid worm, Stylodrilus heringianus	140	-----
10	122***	Midge, Chironomus sp.	20	-----
		Midge, Chironomus riparius	750	-----
9	100	Tubificid worm, Varichaeta pacifica	100	-----
8	80	Tubificid worm, Branchiura sowerbyi	80	-----
7	80	Snail, Amnicola sp.	80	-----
6	50	Crayfish, Orconectes limosus	50	-----
5	28	Guppy, Poecilia reticulata	28	-----
4	20	Crayfish, Faxonella clypeatus	20	-----
3	10	Amphipod, Gammarus sp.	10	-----
2	3.3	Cladoceran, Daphnia magna	3.7	4.498
		Cladoceran, Daphnia pulex	2.9	-----
1	2.9	Cladoceran, Ceriodaphnia reticulata	2.9	-----

* Ranked from most resistant to most sensitive based on Genus Mean Acute Value.

** 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. riparius.

FAV = 3.388 ug/L

CMC = FAV/2 = 1.694 ug/L

FACR = 3.731

FCV = FAV/FACR = (3.388 ug/L)/(3.731) = 0.9081 ug/L = CCC

The CCC of 0.9081 ug/L might not adequately protect such important fishes as the rainbow trout, coho salmon, and bluegill (see above).

References

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1995 UPDATE:
Freshwater Aquatic Life Criterion for Nickel

The new acceptable acute data for nickel are given in Table K1; no new acceptable chronic data were found. These data were used with those given in Tables 1 and 2 of the criteria document for nickel (U.S. EPA 1986) to obtain the values given in Table K2. Some of the SMAVs in Table K2 differ from those given in Table 3 in U.S. EPA (1986) because preference was given to "FT,M" tests in Table K2. Because the toxicity of nickel is hardness-dependent, all acute values in Table K2 have been adjusted to a hardness of 50 mg/L.

Criterion Maximum Concentration (CMC)

The Final Acute Value (FAV) was calculated using the four lowest Genus Mean Acute Values in Table K2, resulting in an FAV of 522 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 261 ug/L, as total recoverable nickel, at a hardness of 50 mg/L. The CMC was related to hardness using the slope of 0.846 that was derived in U.S. EPA (1986):

$$CMC = e^{0.846(\ln \text{hardness}) + 2.255}$$

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). SMACRs were available for two freshwater species and one saltwater species (U.S. EPA 1986). The saltwater ACR was 5.478 and the three are within a factor of 6.5. The FACR was calculated as the geometric mean of the three ACRs and was 17.99. The FCV = FAV/FACR = (522 ug/L)/(17.99) = 29.02 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. Thus the CCC was 29.02 ug/L, as total recoverable nickel, at a hardness of 50 mg/L. The CCC was related to hardness using the slope of 0.846:

$$CCC = e^{0.846(\ln \text{hardness}) + 0.0584}$$

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 nickel does not exceed the numerical value (in ug/L) given by the equation

$$CCC = e^{0.846(\ln \text{hardness}) + 0.0584}$$

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

$$CMC = e^{0.846(\ln \text{hardness}) + 2.255}$$

more than once every three years on the average.

Table K1. New Acute Values for Nickel

Species	Method*	Hardness (mg/L as $CaCO_3$)	Acute Value (ug/L)	Adjusted Acute Value (ug/L)**	Reference
Snail, Physa gyrina	FT,U	26	239	416	Nebeker et al. 1986
Amphipod, Crangonyx pseudogracilis	S,U	50	66,100	66,100	Martin and Holdich 1986
Midge, (1st instar) Chironomus riparis	S,U	55	72,400	66,791	Powlesland and George 1986
Midge, (1st instar) Chironomus riparis	S,U	55	81,300	75,002	Powlesland and George 1986
Midge, (1st instar) Chironomus riparis	S,U	55	84,900	78,323	Powlesland and George 1986
Midge, (2nd instar) Chironomus riparis***	S,U	55	184,000	169,746	Powlesland and George 1986
Midge, (2nd instar) Chironomus riparis***	S,U	55	150,000	138,380	Powlesland and George 1986
Midge, (2nd instar) Chironomus riparis***	S,U	55	174,000	160,521	Powlesland and George 1986

* S = static, FT = flow-through, U = unmeasured.
** Adjusted to a hardness of 50 mg/L using a slope of 0.846.
*** Not used in the calculation of the SMAV because data were available for a more sensitive life stage.

Table K2. Ranked Genus Mean Acute Values for Nickel

Rank*	Genus Mean Acute Value (ug/L)**	Species	Species Mean Acute Value (ug/L)**	Species Mean Acute-Chronic Ratio
21	73208	Midge, Chironomus riparis	73208	-----
20	66100	Amphipod, Crangonyx pseudogracilis	66100	-----
19	43250	Banded killifish, Fundulus diaphanus	43250	-----
18	40460	Stonefly, Acroneuria lycorias	40460	-----
17	30200	Caddisfly Unidentified sp.	30200	-----
16	21320	Goldfish, Carassius auratus	21320	-----
15	21200	Damselfly, Unidentified sp.	21200	-----
14	14100	Worm, Nais sp.	14100	-----
13	13380	Rainbow trout, Oncorhynchus mykiss	13380	-----
12	13000	Amphipod, Gammarus sp.	13000	-----
11	12770	Snail, Amnicola sp.	12770	-----
10	12756	Pumpkinseed, Lepomis gibbosus	7544	-----
		Bluegill, Lepomis macrochirus	21570	-----
9	12180	American eel, Anguilla rostrata	12180	-----
8	9839	Common carp, Cyprinus carpio	9839	-----
7	9661	Guppy, Poecilia reticulata	9661	-----

Table K2. (Cont.)

Rank*	Genus Mean Acute Value (ug/L)**	Species	Species Mean Acute Value (ug/L)**	Species Mean Acute-Chronic Ratio
6	8697	White perch, *Morone americana*	12790	-----
		Striped bass, *Morone saxatilis*	5914	-----
5	6707	Fathead minnow, *Pimephales promelas*	6707	35.58
4	4636	Mayfly, *Ephemerella subvaria*	4636	-----
3	4312	Rock bass, *Ambloplites rupestris*	4312	-----
2	1500	Cladoceran, *Daphnia pulicaria*	2042	-----
		Cladoceran, *Daphnia magna*	1102	29.86
1	416	Snail, *Physa gyrina*	416	-----

* Ranked from most resistant to most sensitive based on Genus Mean Acute Value.
** At hardness = 50 mg/L.

At hardness = 50 mg/L:

FAV = 522 ug/L

CMC = FAV/2 = 261 ug/L

As a function of hardness:

$$CMC = e^{0.846(\ln \text{hardness}) + 2.255}$$

FACR = 17.99

At hardness = 50 mg/L:

FCV = FAV/FACR = (522 ug/L)/(17.99) = 29.02 ug/L = CCC

As a function of hardness:

$$CCC = e^{0.846(\ln \text{hardness}) + 0.0584}$$

References

Martin, T.R., and D.M. Holdich. 1986. The Acute Lethal Toxicity of Heavy Metals to Peracarid Crustaceans (with Particular Reference to Fresh-water Asellids and Gammarids). Water Res. 20:1137-1147.

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1995 UPDATE:
Freshwater Aquatic Life Criterion for Parathion

No new acceptable acute or chronic data for parathion were found. Therefore, the data given in Tables 1 and 2 of the criteria document for parathion (U.S. EPA 1985) were used to obtain the values given in Table L1.

Criterion Maximum Concentration (CMC)

Some of the Genus Mean Acute Values given in Table 3 of U.S. EPA (1985) were changed because of the new taxonomy for salmonids and because only one value was calculated for the genus Chironomus; these changes did not affect the FAV. The Final Acute Value (FAV) was calculated using the four lowest Genus Mean Acute Values given in Table L1, resulting in a FAV of 0.1299 ug/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 0.06495 ug/L.

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). Three Species Mean ACRs were available (Table L1). The ACRs obtained with the resistant fishes were much higher than that obtained with the sensitive cladoceran. To make the FACR appropriate for sensitive species, it was set equal to the ACR of 10.10 obtained with the cladoceran. The FCV = FAV/FACR = (0.1299 ug/L)/(10.10) = 0.01286 ug/L. This value did not need to be lowered to protect a commercially or recreationally important species. The CCC was 0.01286 ug/L.

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 parathion does not exceed 0.01286 ug/L more than once every three years on the average and if the one-hour average concentration does not exceed 0.06495 ug/L more than once every three years on the average.

Table L1. Ranked Genus Mean Acute Values for Parathion

Rank*	Genus Mean Acute Value (ug/L)	Species	Species Mean Acute Value (ug/L)	Species Mean Acute-Chronic Ratio
31	5,230	Tubificid worm, Tubifex sp.	5,230	-----
30	5,230	Tubificid worm, Limnodrilus sp.	5,230	-----
29	2,650	Channel catfish, Ictalurus punctatus	2,650	-----
28	2,223	Goldfish, Carassius auratus	2,223	-----
27	1,838	Brook trout, Salvelinus fontinalis	1,760	-----
		Lake trout Salvelinus namaycush	1,920	-----
26	1,510	Brown trout, Salmo trutta	1,510	-----
25	1,486	Cutthroat trout, Oncorhynchus clarki	1,560	-----
		Rainbow trout, Oncorhynchus gairdneri	1,415	-----
24	1,130	Isopod, Asellus brevicaudus	1,130	-----
23	1,000	Western chorus frog, Pseudacris triseriata	1,000	-----
22	839.6	Fathead minnow, Pimephales promelas	839.6	79.45**
21	688.7	Green sunfish, Lepomis cyanellus	930	-----
		Bluegill, Lepomis macrochirus	510	2121**
20	620	Largemouth bass, Micropterus salmoides	620	-----
19	320	Mosquitofish, Gambusia affinis	320	-----
18	<250	Crayfish, Procambarus sp.	<250	-----

Table L1. (Cont.)

Rank*	Genus Mean Acute Value (ug/L)	Species	Species Mean Acute Value (ug/L)	Species Mean Acute-Chronic Ratio
17	56	Guppy, Poecilia reticulata	56	-----
16	15	Mayfly, Hexagenia bilineata	15	-----
15	7.0	Beetle, Peltodytes spp.	7.0	-----
14	5.4	Stonefly, Pteronarcys californica	5.4	-----
13	4.2	Stonefly, Pteronarcella badia	4.2	-----
12	3.0	Damselfly, Lestes congener	3.0	-----
11	2.9	Stonefly, Acroneuria pacifica	2.9	-----
10	2.739	Prawn, Palaemonetes kadiakensis	2.739	-----
9	2.227	Mayfly, Cloeon dipterum	2.227	-----
8	1.697***	Midge, Chironomus tentans	31	-----
		Midge, Chironomus riparius	1.697	-----
7	1.5	Stonefly, Claassenia sabulosa	1.5	-----
6	1.127	Amphipod, Gammarus fasciatus	0.3628	-----
		Amphipod, Gammarus lacustris	3.5	-----
5	0.8944	Phantom midge, Chaoborus sp.	0.8944	-----

Table L1. (Cont.)

Rank*	Genus Mean Acute Value (ug/L)	Species	Species Mean Acute Value (ug/L)	Species Mean Acute-Chronic Ratio
4	0.7746	Cladoceran, *Daphnia magna*	1.0	10.10
		Cladoceran, *Daphnia pulex*	0.60	-----
3	0.64	Damselfly, *Ischnura verticalis*	0.64	-----
2	0.47	Cladoceran, *Simocephalus serrulatus*	0.47	-----
1	0.04	Crayfish, *Orconectes nais*	0.04	-----

* Ranked from most resistant to most sensitive based on Genus Mean Acute Value.

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

*** This GMAV was set equal to the lower SMAV due to the large range in the SMAVs in this genus.

FAV = 0.1299 ug/L

CMC = FAV/2 = 0.06495 ug/L

FACR = 10.10

FCV = FAV/FACR = (0.1299 ug/L)/(10.10) = 0.01286 ug/L = CCC

References

U.S. EPA. 1986. Ambient Aquatic Life Water Quality Criteria for Parathion - 1986. EPA 440/5-86-007. National Technical Information Service, Springfield, VA.

1995 UPDATE:
Freshwater Aquatic Life Criterion for Pentachlorophenol

No new acceptable acute or chronic data for pentachlorophenol were found. Therefore, the data given in Tables 1 and 2 of the criteria document for pentachlorophenol (U.S. EPA 1986) were used to obtain the values given in Table M1. Because the toxicity of pentachlorophenol is pH-dependent, all acute values in Table M1 have been adjusted to a pH of 6.5.

Criterion Maximum Concentration (CMC)

Some of the Genus Mean Acute Values given in Table 3 of U.S. EPA (1985) were changed because of the new taxonomy for salmonids and because the values for *Jordanella floridae* and *Rana catesbeiana* had been incorrectly adjusted to a pH of 6.5 and because the SMAV for *Gammarus pseudolimnaeus* had been calculated incorrectly. The Final Acute Value (FAV) was calculated using the four lowest Genus Mean Acute Values given in Table M1, resulting in a FAV of 10.56 ug/L at a pH of 6.5. 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 5.28 ug/L at a pH of 6.5. The CMC was related to pH using the slope of 1.005 that was derived in U.S. EPA (1986):

$$CMC = e^{1.005(pH) - 4.869}$$

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). Six Species Mean ACRs were available (Table M1), but two of them were "greater than" values. The range of the other four was less than a factor of 6. The FACR was calculated as the geometric mean of the four similar SMACRs and was 2.608. The FCV = FAV/FACR = (10.56 ug/L)/(2.608) = 4.049 ug/L at a pH of 6.5. This value did not need to be lowered to protect a commercially or recreationally important species. The CCC was 4.049 ug/L at a pH of 6.5. The CCC was related to pH using the slope of 1.005:

$$CCC = e^{1.005(pH) - 5.134}$$

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 pentachlorophenol does not exceed the numerical value (in ug/L) given by the equation

$$CCC = e^{1.005(pH) - 5.134}$$

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

$$CMC = e^{1.005(pH) - 4.869}$$

more than once every three years on the average.

Table M1. Ranked Genus Mean Acute Values for Pentachlorophenol

Rank*	Genus Mean Acute Value (ug/L)**	Species	Species Mean Acute Value (ug/L)**	Species Mean Acute-Chronic Ratio
32	>43920	Crayfish, Orconectes immunis	>43920	-----
31	11260	Midge, Tanytarsus dissimilis	11260	-----
30	10610	Sciomyzid, Sepedon fuscipennis	10610	-----
29	417.7	Tubificid worm, Rhyacodrilus montana	417.7	-----
28	408.2	Tubificid worm, Stylodrilus heringianus	408.2	-----
27	403.2	Snail, Gilila altilis	403.2	-----
26	361.6	Tubificid worm, Spirosperma ferox	239.5	-----
		Tubificid worm, Spirosperma nikoiskyl	545.8	-----
25	317.5	Tubificid worm, Quistadrilus multisetosus	317.5	-----
24	306.7	Flagfish, Jordanella floridae	306.7	-----
23	224.2	Tubificid worm, Tubifex tubifex	224.2	-----
22	195.4	Guppy, Poecilia reticulata	195.4	-----
21	182.5	Tubificid worm, Limnodrilus hoffmeisteri	182.5	-----
20	172.1	Amphipod, Crangonyx pseudogracilis	172.1	-----
19	155.9	Tubificid worm, Branchiura sowerbyi	155.9	-----
18	132.1	Snail, Physa gyrina	132.1	>10.27***

Table M1. (Cont.)

Rank*	Genus Mean Acute Value (ug/L)**	Species	Species Mean Acute Value (ug/L)**	Species Mean Acute-Chronic Ratio
17	105.0	Largemouth bass, Micropterus salmoides	105.0	-----
16	91.48	Amphipod, Gammarus pseudolimnaeus	91.48	-----
15	87.48	Amphipod, Hyalella azteca	87.48	-----
14	78.10	Cladoceran, Daphnia pulex	90.83	-----
		Cladoceran, Daphnia magna	67.15	2.5
13	67.13	Cladoceran, Ceriodaphnia reticulata	67.13	>15.79***
12	65.53	Goldfish, Carassius auratus	65.53	-----
11	63.11	Fathead minnow, Pimephales promelas	63.11	4.535
10	60.50	Mosquitofish, Gambusia affinis	60.50	-----
9	60.43	Snail, Aplexa hypnorum	60.43	-----
8	58.47	Tubificid worm, Varichaeta pacifica	58.47	-----
7	57.72	Cladoceran, Simocephalus vetulus	57.72	0.8945
6	56.41	Bluegill, Lepomis macrochirus	56.41	-----
5	34.13	Brook trout, Salvelinus fontinalis	34.13	-----
4	33.91	Bullfrog, Rana catesbeiana	33.91	-----

Table M1. (Cont.)

Rank*	Genus Mean Acute Value (ug/L)**	Species	Species Mean Acute Value (ug/L)**	Species Mean Acute-Chronic Ratio
3	31.26	Rainbow trout, Oncorhynchus mykiss	35.34	4.564
		Coho salmon, Oncorhynchus kisutch	31.82	-----
		Sockeye salmon, Oncorhynchus nerka	32.85	-----
		Chinook salmon, Oncorhynchus tshawytscha	25.85	-----
2	26.54	Channel catfish, Ictalurus punctatus	26.54	-----
1	4.355	Common carp, Cyprinus carpio	4.355	-----

* Ranked from most resistant to most sensitive based on Genus Mean Acute Value.
** At pH = 6.5.
*** Not used in the calculation of the Final Acute-Chronic Ratio.

At pH = 6.5:

FAV = 10.56 ug/L

CMC = FAV/2 = 5.28 ug/L

As a function of pH:

$$CMC = e^{1.005(pH) - 4.869}$$

FACR = 2.608

At pH = 6.5:

FCV = FAV/FACR = (10.56 ug/L)/(2.608) = 4.049 ug/L = CCC

As a function of pH:

$$CCC = e^{1.005(pH) - 5.134}$$

References

U.S. EPA. 1986. Ambient Aquatic Life Water Quality Criteria for Pentachlorophenol. EPA 440/5-88-009. National Technical Information Service, Springfield, VA.

1995 UPDATE:
Freshwater Aquatic Life Criterion for Selenium

The new acceptable acute data for selenium are given in Table N1; no new acceptable chronic data were found. These new data were used with those given in Tables 1 and 2 of the criteria document for selenium (U.S. EPA 1987) to obtain the values given in Tables N2 and N3.

Selenium(IV):

Criterion Maximum Concentration (CMC)

The Final Acute Value (FAV) was calculated using the four lowest Genus Mean Acute Values given in Table N2, resulting in a FAV of 371.8 ug/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 185.9 ug/L.

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). Four Species Mean ACRs were available (Table N2), but the one determined with the acutely resistant species was higher than the other three; the three were within a factor of 2.4. The FACR was calculated as the geometric mean of the three and was 7.998. The FCV = FAV/FACR = (371.8 ug/L)/(7.998) = 46.49 ug/L. As in U.S. EPA (1987), this value was lowered to 27.6 ug/L to protect the commercially and recreationally important rainbow trout. The CCC was 27.6 ug/L.

Selenium(VI):

Criterion Maximum Concentration (CMC)

The Final Acute Value (FAV) was calculated using the four lowest Genus Mean Acute Values given in Table N3, resulting in a FAV of 25.066 ug/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 12.533 ug/L.

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). Three Species Mean ACRs were available (Table N3), and they increased as the acute sensitivities of the species increased. To make the FACR appropriate for sensitive species, it was set equal to the SMACR of 2.651 for the sensitive Daphnia magna. The FCV = FAV/FACR = (25.066 ug/L)/(2.651) = 9.455 ug/L. This value did not need to be lowered to protect a commercially or recreationally important species. The CCC was 9.455 ug/L.

Total selenium:

As discussed in U.S. EPA (1987), field studies conducted on Belews Lake in North Carolina suggested that selenium might be more toxic to certain species of freshwater fish than had been observed in laboratory chronic toxicity tests. Based upon these field studies and some laboratory studies, the CCC for total selenium was set at 5 ug/L. The Final Acute-Chronic Ratio for total selenium was calculated as the geometric mean of the six ACRs in Tables N2 and N3 that are between 2.5 and 16.5 and was 7.737. The FAV was calculated by multiplying the CCC by the FACR and was 38.68 ug/L. The CMC was calculated by dividing the FAV by 2, resulting in a CMC of 19.34 ug/L as total recoverable selenium.

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 selenium does not exceed 5 ug/L more than once every three years on the average and if the one-hour average concentration does not exceed 19.34 ug/L more than once every three years on the average.

Table N1. New Acute Values for Selenium

Species	Method*	Chemical	Acute Value (ug/L)	Reference
Cladoceran, Daphnia magna	S,U	Na-selenite [Selenium(IV)]	680	Johnston 1987
Cladoceran, Daphnia magna	S,U	Na-selenate [Selenium(VI)]	750	Johnston 1987

* S = static, U = unmeasured.

Table N2. Ranked Genus Mean Acute Values for Selenium(IV)

Rank*	Genus Mean Acute Value (ug/L)	Species	Species Mean Acute Value (ug/L)	Species Mean Acute-Chronic Ratio
22	203000	Leech, Nephelopsis obscure	203000	-----
21	42500	Midge, Tanytarsus dissimilis	42500	-----
20	35000	Common carp, Cyprinus carpio	35000	-----
19	34910	Snail, Aplexa hypnorum	34910	-----
18	30176	White sucker, Catostomus commersoni	30176	-----
17	28500	Bluegill, Lepomis macrochirus	28500	-----
16	26100	Goldfish, Carassius auratus	26100	-----
15	25934	Midge, Chironomus plumosus	25934	-----
14	24100	Snail, Physa sp.	24100	-----
13	13600	Channel catfish, Ictalurus punctatus	13600	-----
12	12600	Mosquitofish, Gambusia affinis	12600	-----
11	11700	Yellow Perch, Perca flavescens	11700	-----
10	10490	Rainbow Trout, Oncorhynchus mykiss	10490	141.5**
9	10200	Brook trout, Salvelinus fontinalis	10200	-----
8	6500	Flagfish, Jordanella floridae	6500	-----
7	2704	Amphipod, Gammarus pseudolimnaeus	2704	-----

Table N2. (Cont.)

Rank*	Genus Mean Acute Value (ug/L)	Species	Species Mean Acute Value (ug/L)	Species Mean Acute-Chronic Ratio
6	1796	Cladoceran, Daphnia magna	834	13.31
		Cladoceran, Daphnia pulex	3870	5.586
5	1783	Striped bass, Morone saxatilis	1783	-----
4	1700	Hydra, Hydra sp.	1700	-----
3	1601	Fathead minnow, Pimephales promelas	1601	6.881
2	<603.6	Cladoceran, Ceriodaphnia affinis	<603.6	-----
1	340	Amphipod, Hyalella ázteca	340	-----

* Ranked from most resistant to most sensitive based on Genus Mean Acute Value.

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

FAV = 371.8 ug/L

CMC = FAV/2 = 185.9 ug/L

FACR = 7.998

FCV = FAV/FACR = (371.8 ug/L)/(7.998) = 46.49 ug/L

Lowered to protect rainbow trout:

FCV = 27.6 ug/L = CCC

Table N3. Ranked Genus Mean Acute Values for Selenium(VI)

Rank*	Genus Mean Acute Value (ug/L)	Species	Species Mean Acute Value (ug/L)	Species Mean Acute-Chronic Ratio
11	442000	Leech, Hephelopsis obscura	442000	-----
10	193000	Snail, Aplexa hypnorum	193000	-----
9	66000	Channel catfish, Ictalurus punctatus	66000	-----
8	63000	Bluegill, Lepomis macrochirus	63000	-----
7	47000	Rainbow trout, Oncorhynchus mykiss	47000	16.26
6	20000	Midge, Paratanytarsus parthenogeneticus	20000	-----
5	7300	Hydra, Hydra sp.	7300	-----
4	5500	Fathead minnow, Pimephales promelas	5500	9.726
3	760	Amphipod, Hyalella azteca	760	-----
2	550.1	Cladoceran, Daphnia magna	1230	2.651
		Cladoceran, Daphnia pulicaria	246	-----
1	65.38	Amphipod, Gammarus pseudolimnaeus	65.38	-----

* Ranked from most resistant to most sensitive based on Genus Mean Acute Value.

FAV = 25.066 ug/L

CMC = FAV/2 = 12.533 ug/L

FACR = 2.651

FCV = FAV/FACR = (25.066 ug/L)/(2.651) = 9.455 ug/L = CCC

References

Johnston, P.A. 1987. Acute Toxicity of Inorganic Selenium to Daphnia magna (Straus) and the Effect of Sub-acute Exposure upon Growth and Reproduction. Aquatic Toxicol. 10:335-352.

U.S. EPA. 1987. Ambient Aquatic Life Water Quality Criteria for Selenium. EPA 440/5-87-006. National Technical Information Service, Springfield, VA.

1995 UPDATE:
Freshwater Aquatic Life Criterion for Zinc

The new acceptable acute data for zinc are given in Table O1; no new acceptable chronic data were found. These data were used with those given in Tables 1 and 2 of the criteria document for zinc (U.S. EPA 1987) to obtain the values given in Table O2. Because the toxicity of zinc is hardness-dependent, all acute values in Table O2 have been adjusted to a hardness of 50 mg/L.

Criterion Maximum Concentration (CMC)

The Final Acute Value (FAV) was calculated using the four lowest Genus Mean Acute Values in Table O2, resulting in an FAV of 133.2 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 66.6 ug/L, as total recoverable zinc, at a hardness of 50 mg/L. The CMC was related to hardness using the slope of 0.8473 that was derived in U.S. EPA (1987):

$$CMC = e^{0.8473(\ln hardness) + 0.884}$$

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). SMACRs were available for seven species (Table O2), but three were for resistant species and one was a "less than" value. The other three were within a factor of 10.4. The FACR was calculated as the geometric mean of the three SMACRs and was 1.994. According to the methodology, the FACR cannot be less than 2. The FCV = FAV/FACR = (133.2 ug/L)/(2) = 66.6 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. Thus the CCC was 66.6 ug/L, as total recoverable zinc, at a hardness of 50 mg/L and equals the CMC. The CCC was related to hardness using the slope of 0.8473:

$$CCC = e^{0.8473(\ln hardness) + 0.884}$$

When it equals the CMC, the CCC is irrelevant because the CMC has a shorter averaging period.

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 one-hour average concentration of zinc does not exceed the numerical value (in ug/L) given by the equation

$$CMC = e^{0.8473(\ln \text{hardness}) + 0.884}$$

more than once every three years on the average.

Table O1. New Acute Values for Zinc

Species	Method*	Hardness (mg/L as $CaCO_3$)	Acute Value (ug/L)	Adjusted Acute Value (ug/L)**	Reference
Frog, Xenopus laevis	S,M	100	34500	19176	Dawson et al. 1988
Cladoceran, Daphnia magna	S,U	300	1100	241	Berglind and Dave 1984

* S = Static, M = measured, U = unmeasured.
** Adjusted to a hardness of 50 mg/L using slope = 0.8473.

Table O2. Ranked Genus Mean Acute Values for Zinc.

Rank*	Genus Mean Acute Value (ug/L)**	Species	Species Mean Acute Value (ug/L)**	Species Mean Acute-Chronic Ratio
36	88960	Damselfly, Argia sp.	88960	-----
35	19800	Amphipod, Crangonyx pseudogracilis	19800	-----
34	19176	Frog, Xenopus laevis	19176	-----
33	18400	Worm, Nais sp.	18400	-----
32	17940	Banded killifish, Fundulus diaphanus	17940	-----
31	16820	Snail, Amnicola sp.	16820	-----
30	13630	American eel, Anguilla rostrata	13630	-----
29	10560	Pumpkinseed, Lepomis gibbosus	18790	-----
		Bluegill, Lepomis macrochirus	5937	-----
28	10250	Goldfish, Carassius auratus	10250	-----
27	9712	Worm, Lumbriculus variegatus	9712	-----
26	8157	Isopod, Asellus bicrenata	5731	-----
		Isopod, Asellus communis	11610	-----
25	8100	Amphipod, Gammarus sp.	8100	-----
24	7233	Common carp, Cyprinus carpio	7233	-----
23	6580	Northern squawfish, Ptychocheilus oregonensis	6580	-----
22	6053	Guppy, Poecilia reticulata	6053	-----

Table O2. (Cont.)

Rank*	Genus Mean Acute Value (ug/L)**	Species	Species Mean Acute Value (ug/L)**	Species Mean Acute-Chronic Ratio
21	6000	Golden shiner, *Notemigonus crysoleucas*	6000	-----
20	5228	White sucker, *Catostomus commersoni*	5228	-----
19	4900	Asiatic clam, *Corbicula fluminea*	4900	-----
18	4341	Southern platyfish, *Xiphophorus maculatus*	4341	-----
17	3830	Fathead minnow, *Pimephales promelas*	3830	5.644***
16	3265	Isopod, *Lirceus alabamae*	3265	-----
15	2176	Atlantic salmon, *Salmo salar*	2176	-----
14	2100	Brook trout, *Salvelinus fontinalis*	2100	2.335***
13	1707	Bryozoan, *Lophopodella carteri*	1707	-----
12	1672	Flagfish, *Jordanella floridae*	1672	41.2***
11	1607	Bryozoan, *Plumatella emarginata*	1607	-----
10	1578	Snail, *Helisoma campanulatum*	1578	-----
9	1353	Snail, *Physa gyrina*	1683	-----
		Snail, *Physa heterostropha*	1088	-----
8	1307	Bryozoan, *Pectinatella magnifica*	1307	-----
7	>1264	Tubificid worm, *Limnodrilus hoffmeisteri*	>1264	-----

Table O2. (Cont.)

Rank*	Genus Mean Acute Value (ug/L)**	Species	Species Mean Acute Value (ug/L)**	Species Mean Acute-Chronic Ratio
6	931.3	Rainbow trout, *Oncorhynchus mykiss*	689.3	1.554
		Coho salmon, *Oncorhynchus kisutch*	1628	-----
		Sockeye salmon, *Oncorhynchus nerka*	1502	<6.074***
		Chinook salmon, *Oncorhynchus tshawytscha*	446.4	0.7027
5	790	Mozambique tilapia, *Tilapia mossambica*	790	-----
4	299.8	Cladoceran, *Daphnia magna*	355.5	7.26
		Cladoceran, *Daphnia pulex*	252.9	-----
3	227.8	Longfin dace, *Agosia chrysogaster*	227.8	-----
2	119.4	Striped bass, *Morone saxatilis*	119.4	-----
1	93.95	Cladoceran, *Ceriodaphnia dubia*	174.1	-----
		Cladoceran, *Ceriodaphnia reticulata*	50.70	-----

* Ranked from most resistant to most sensitive based on Genus Mean Acute Value.

** At hardness = 50 mg/L.

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

At hardness = 50 mg/L:

FAV = 133.2 ug/L

CMC = FAV/2 = 66.6 ug/L

As a function of hardness:

$$CMC = e^{0.8473(\ln hardness) + 0.884}$$

FACR = 1.994 but was raised to 2

At hardness = 50 mg/L:

FCV = FAV/FACR = (133.2 ug/L)/(2) = 66.6 ug/L = CCC

As a function of hardness:

$$CCC = e^{0.8473(\ln hardness) + 0.884}$$

References

Berglind, R., and G. Dave. 1984. Acute Toxicity of Chromate, DDT, PCP, TPBS, and Zinc to Daphnia magna Cultured in Hard and Soft Water. Bull. Environ. Contam. Toxicol. 33:63-68.

Dawson, D.A., E.F. Stebler, S.L. Burks, and J.A. Bantle. 1988. Evaluation of the Developmental Toxicity of Metal-Contaminated Sediments Using Short-Term Fathead Minnow and Frog Embryo-Larval Assays. Environ. Toxicol. Chem. 7:27-34.

U.S. EPA. 1987. Ambient Aquatic Life Water Quality Criteria for Zinc. EPA 440/5-87-003. National Technical Information Service, Springfield, VA.

STATE OF NEW MEXICO
WATER QUALITY CONTROL COMMISSION

IN THE MATTER OF: PROPOSED AMENDMENTS TO STANDARDS FOR INTERSTATE AND INTRASTATE SURFACE WATERS 20.6.4 NMAC

WQCC 20-51(R)

DIRECT TECHNICAL TESTIMONY OF KRIS BARRIOS

I. INTRODUCTION

My name is Kris Barrios and I present this written testimony (**NMED Exhibit 2**) on behalf of the New Mexico Environment Department ("Department" or "NMED") Surface Water Quality Bureau ("SWQB") concerning the SWQB's proposed amendments to the State of New Mexico's Standards for Interstate and Intrastate Surface Waters ("Standards"), codified as Title 20, Chapter 6, Part 4 of the New Mexico Administrative Code (20.6.4 NMAC). Section 303(c)(1) of the federal Clean Water Act ("CWA") (33 U.S.C. § 1313) (**EXHIBIT 11**) requires each state to hold a public hearing at least once every three years to review and modify, as appropriate, its water quality standards, in a process known as the "Triennial Review" of the State's Standards. My testimony outlines the reasoning behind the following proposed changes:

- updated or new definitions for "Contaminants of Emerging Concern", "Persistent Toxic Pollutants", and "Unclassified Waters of the State" in 20.6.4.7 NMAC;
- an update to 20.6.4.13 NMAC, General Criteria that clarifies the substances considered under the narrative criterion for toxic pollutants;
- addition of cyanobacteria toxin criteria to the Primary Contact designated use, 20.6.4.900(D) NMAC;
- updates and additions to numeric criteria in 20.6.4.900(J)(1) NMAC; and
- reference and grammatical corrections to various sections.

My testimony also provides the reasoning for numeric criteria that were reviewed but not proposed as amendments in this Triennial Review.

II. QUALIFICATIONS

I am currently employed as the Program Manager for the Monitoring, Assessment, and Standards Section for the SWQB and have held this position since August 2017. I began work with the Department in October 2015 as the Monitoring Team Supervisor within the SWQB. Before employment with the Department, I supervised the water quality and hydrologic monitoring program for the Northwest Florida Water Management District ("NWFWMD"). In other capacities, I have served as a hydrogeologist responsible for ground water and surface water monitoring, a project geologist for petroleum storage tank investigations, an environmental scientist working on ground water contamination delineation, and a laboratory technician.

I have a Bachelor of Science degree in Geology from Florida State University with a minor in mathematics. I am also a licensed Professional Geologist (Florida License 2861). My publications include Barrios, K., 2011. *Nitrate Sources of Springs Discharging to Merritt's Mill Pond, Jackson County, FL*. NWFWMD TFR 2011-1, Barrios, K., 2006. *St. Marks River and Wakulla River Springs Inventory, Leon and Wakulla Counties, Florida*. NWFWMD WSR 06-03, Barrios, K. and DeFosset, K., 2005. *Ground Water Chemical Characterization of Jackson Blue Spring and Wakulla Springs, Florida*. NWFWMD WSR 05-01, among others. I have provided my updated resume as **NMED Exhibit 6**.

III. AMENDMENTS DESCRIBING WATERS

The Department proposes to move the definition for "unclassified waters of the state" from 20.6.4.11(H) NMAC to 20.6.4.7(U) NMAC to provide a consistent location for definitions. This change is intended to complement the definition of "classified water of the state", 20.6.4.7(C)(3)

NMAC. The State has used a definition for "classified water the state" since 1995; however, before adopting designated uses for the State's unclassified waters, there was no definition for the term "unclassified waters of the state". The term "non-classified" or "unclassified" was used only to describe the applicability of water quality standards for those waters that were not "classified". Since the State adopted designated uses for unclassified perennial and non-perennial waters, the term now serves a functional purpose as a definition. However, the State kept the language under the section entitled "Applicability of Water Quality Standards" (20.6.4.11 NMAC). It is more appropriate and consistent with other defined terms to relocate the definition to 20.6.4.7 NMAC. The proposed change does not alter the meaning nor affect the implementation of the term.

IV. AMENDMENTS ASSOCIATED WITH CRITERIA

A. General Criteria

1. Toxic Pollutants

The Department proposes the addition of "contaminants of emerging concern" and the toxic pollutants listed in 20.6.2.7(T)(2) NMAC to the general criteria for toxic pollutants, 20.6.4.13(F) NMAC. The definition for "toxic pollutants", located in 20.6.4.7(T) NMAC, refers to a pollutant or combination of pollutants that cause adverse impacts upon exposure to organisms or their offspring. The Department proposes adding "contaminants of emerging concern" to the general criterion for toxic pollutants. These compounds include pollutants that are known or suspected toxins but do not have numeric criteria. Similarly, the definition of "toxic pollutants" under the State's Regulations for Ground and Surface Water Protection (20.6.2.7(T)(2) NMAC) includes compounds that have numeric criteria in 20.6.4 NMAC, as well as those that do not. Since the State identifies these compounds as toxic pollutants, the Department proposes adding a reference to the toxic pollutants listed in 20.6.2.7(T)(2) NMAC to 20.6.4.13(F) NMAC. Adding language to clarify that the general criterion for toxic pollutants in 20.6.4.13(F) NMAC includes contaminants of emerging concern and the toxic pollutants listed in 20.6.2.7(T)(2) NMAC will aid in implementing water quality standards and upholding the goals and objectives of the Clean Water Act.

2. Addition of a definition for "Contaminants of Emerging Concern"

The Department proposes to add a definition for "contaminants of emerging concern" or "CECs" to 20.6.4.7(C) NMAC to identify pollutants recognized as toxic to or have other harmful effects on aquatic life or other organisms. The Department bases the proposed definition on information provided at the U.S. Environmental Protection Agency's ("EPA's") website for contaminants of emerging concern (**EXHIBIT 35**).

The Standards include narrative criteria and numeric criteria. The narrative (i.e., "general") criteria are statements that describe the desired water quality goal, such as waters being "free from" pollutants like oil and scum, color and odor, and other substances that can harm people and fish. These criteria protect water bodies from contaminants for which numeric criteria are difficult to specify. Since "contaminants of emerging concern" is a proposed addition to the general criteria for toxic pollutants in 20.6.4.13(F)(1) NMAC, a definition is necessary to provide an attributable reference. Although EPA has not developed numeric criteria for CECs, clarification that NMED's general criterion for toxic pollutants regulates this group of pollutants provides greater clarity for implementing water quality standards.

3. Addition of a definition for "Persistent Toxic Pollutants"

The Department proposes to add a definition for "persistent toxic pollutants" to 20.6.4.7(P) NMAC to clarify its meaning since the term describes certain pollutants in 20.6.4.900(J)(1) NMAC. The term references those toxic pollutants, as defined in 20.6.4.7(T)(2) NMAC, that persist in the environment or do not metabolize in a living organism and, as a result, bioaccumulate in organisms over time, causing harm or adverse impacts to human health and the environment. The designation of persistent toxic pollutants to human health-organism only criteria results in the application of that criterion to all tributaries of waters with designated, existing, or attainable aquatic life uses. Also, chronic criteria for persistent toxic pollutants are applicable for the limited aquatic life designated use. The addition of a definition for "persistent toxic pollutants" does not alter the implementation of water quality standards.

B. Numeric Criteria, 20.6.4.900 NMAC

40 Code of Federal Regulations ("C.F.R.") Section 131.20(a) (**NMED EXHIBIT 21**) requires states to review and, if appropriate, modify and adopt applicable water quality standards. States are required, pursuant to 40 C.F.R. § 131.11(b)(1) (**NMED Exhibit 25**), to adopt numeric water quality criteria that are either based on Section 304(a) of the CWA (33 U.S.C. § 1314), develop modified criteria from those in Section 304(a) of the CWA (33 U.S.C. § 1314) to reflect site-specific conditions, or develop criteria based on other scientifically defensible methods (**NMED Exhibit 12**). Based on EPA's published recommended criteria, the State proposes to adopt criteria for the primary contact recreational designated use and aquatic life designated use.

1. Recreational Use Primary Contact Numeric Criteria

In May 2019, EPA published its nationally recommended Human Health Recreational Ambient Water Quality Criteria for Microcystins and Cylindrospermopsin (**EXHIBIT 36**). The EPA based the new criteria on the latest scientific knowledge about the potential human exposure risk effects and the toxins' adverse effects to the liver and kidney, development, and the reproductive, respiratory, and digestive systems. These effects range from acute short-term to chronic long-term health effects. Under 40 C.F.R. § 131.20 (**NMED Exhibit 21**), and Section

304(a) of the CWA (33 U.S.C. § 1314) (**NMED Exhibit 12**), the Department proposes to adopt numeric criteria for the State's designated recreational primary contact use for toxins affiliated with harmful algal blooms, microcystins, and cylindrospermopsin.

The EPA includes magnitude, duration, and frequency components in its recommended criteria for microcystins and cylindrospermopsin (**EXHIBIT 36**). The recommendation for recreational water quality criteria is a maximum concentration for both microcystins and cylindrospermopsin with a duration of one day in a 10-day assessment period and a frequency of no more than three excursions per recreational season in more than one year. Based on the EPA's Draft Technical Support Document (**EXHIBIT 37**) for implementing the recommended recreational criteria, EPA is likely to provide states the flexibility to define the length of the recreational season and recurrence frequency for criteria associated with microcystins and cylindrospermopsin. Since the recreational season in New Mexico varies by region, elevation, and waterbody, the Department proposes to use a 12-month period instead of a defined recreational season. The Department also proposes a 12-month period for the frequency component of the criterion. Adding these criteria for waters with a primary contact designated use will enhance protections directly associated with human health. The Department may require entities with an National Pollutant Discharge Elimination System ("NPDES") permit to increase monitoring efforts to demonstrate compliance with microcystin and cylindrospermopsin permit limits.

2. Acute and Chronic Aquatic Life Numeric Criteria

The Department proposes the adoption of recommended EPA criteria in the Table of Numeric Criteria, 20.6.4.900(J)(1) NMAC. In accordance with 40 C.F.R. § 131.11 (**NMED Exhibit 25**), states must adopt those water quality criteria that protect the designated uses. States should base numeric criteria on either CWA Section 304(a) guidance, CWA Section 304(a) guidance modified to reflect site-specific conditions, or other scientifically defensible methods. As part of the Triennial Review, and according to 40 C.F.R. § 131.20 (**NMED Exhibit 21**), if a State does not adopt new or revised criteria for parameters for which EPA has published new or updated CWA Section 304(a) criteria recommendations (**NMED Exhibit 12**), then the State shall provide an explanation when it submits the results of its Triennial Review to the Regional Administrator.

The State's water quality standards have a list of use-specific numeric criteria identified in 20.6.4.900(J)(1) NMAC. The table of use-specific criteria arranges the pollutant on the first column and the designated use numeric criterion in subsequent columns. Those columns (designated uses) that do not have a value do not have an associated numeric criterion for that pollutant.

There are three different types of criteria for the protection of aquatic life: those associated with acute exposure, those associated with chronic exposures, and those based on human consumption of an aquatic organism (human health-organism only). Although the human health-organism only exposure endpoint is the human consumption of an aquatic organism, these criteria are considered aquatic life protections, and the numeric criteria are, like the other criteria, based on concentrations in water, unless described otherwise.

The pollutants for human health-organism only are of particular concern because they are either persistent in the environment and bioaccumulate in the organism and/or they are carcinogenic, meaning they have been determined to cause cancer at a higher rate than what would be assumed normal for the general population. Because these endpoints impact both establishment of these numeric criteria and the implementation of the water quality standards, the last column provides a delineation of the exposure endpoints for these pollutants. The State has 108 numeric criteria for human health-organism only pollutants, 60 of which have a carcinogenic endpoint.

Human health-organism only criteria were last updated in the 2010 Triennial Review. In 2015, EPA updated human health criteria for approximately 94 constituents. As part of this Triennial Review, the Department compared the State's numeric human health-organism only criteria to EPA's Section 304(a) criteria **(NMED Exhibit 38)**. The evaluation concluded that of the 108 pollutants with human health-organism only criteria listed in 20.6.4.900(J)(1) NMAC, 23 are equivalent to EPA Section 304(a) criteria and required no amendment, 60 pollutants have EPA Section 304(a) criteria more stringent than the State's, and 25 pollutants have EPA Section 304(a) criteria less stringent than the State's. In addition, 14 pollutants are listed on EPA Section 304(a) guidance but not adopted by the State. Adopting the proposed criteria into the State's water quality standards will result in 122 human health-organism only aquatic life criteria. For those criteria derived from a cancer-causing endpoint, the State has adjusted the numeric value by one order of magnitude to account for New Mexico's lifetime risk of more than one cancer per 100,000 exposed persons (20.6.4.13(F)(2)(a)) in comparison to EPA's lifetime risk of more than one cancer per 1,000,000 exposed persons.

For benzene, EPA's recommended criterion has a range of 16-58 micrograms per liter ("µg/L"), which is more stringent than the current 510 µg/L. Based on benzene's carcinogenic effects, EPA recommends the lower range of the criterion to protect human health (**EXHIBIT 39**). The Department proposes adopting the recommended lower range, increased by one order of to account for New Mexico's lifetime risk of more than one cancer per 100,000 exposed persons (20.6.4.13(F)(2)(a)20.6.2 NMAC) in comparison to EPA's lifetime risk of more than one cancer per 1,000,000 exposed persons, resulting in a proposed criterion of 160 µg/L.

The recommended criteria published by EPA, in accordance with Section 304(a) of the CWA (33 U.S.C. § 1314) (**NMED Exhibit 12**), includes criteria protecting acute and chronic aquatic life for 61 pollutants, of which 30 have narrative criteria only (**NMED Exhibit 40**). The Department compared these numeric aquatic life criteria to those criteria listed in 20.6.4.900(J)(1) NMAC (**NMED Exhibit 41**). Of the 31 pollutants listed in EPA's recommended criteria with an acute numeric EPA Section 304(a) criterion, six pollutants do not have numeric criteria under the State's water quality standards: chlorpyrifos, chloride, parathion, tributyltin, acrolein, and carbaryl. Fourteen pollutants have a chronic numeric aquatic life criterion listed in EPA's recommended criteria, but do not have numeric criteria under the State's water quality standards. These pollutants include those identified above for acute aquatic life as well as alkalinity, demeton, guthion, hydrogen sulfide, iron, malthion, methoxychlor and mirex. As part of the Triennial Review requirements, the Department proposes adopting the above noted EPA recommended criteria for acute and chronic aquatic life use.

Eight pollutants listed in EPA's recommended guidance for acute and chronic aquatic life criteria have hardness-based criteria under 20.6.4.900 NMAC. These constituents are evaluated and addressed in the testimony of Jennifer Fullam (**EXHIBIT 4**).

The Department proposes to take no action on the EPA's recommended aquatic life criteria for the following pollutants: aluminum, arsenic, manganese, and selenium. The Department provides its reasoning in section IV(B)(3) of this testimony.

There are no pollutants within 20.6.4.900(J)(1) NMAC with chronic numeric aquatic life criteria that are more stringent than EPA's recommended criteria. However, polychlorinated biphenyls ("PCBs") and selenium have acute criteria listed in 20.6.4.900(J)(1) NMAC but do not have associated acute criteria in EPA's recommended aquatic life criteria guidance. The

Department is not proposing a change in PCBs criteria; however, the Department proposes moving the criteria to fit alphabetically within organic pollutants in Table 20.6.4.900(J)(1) NMAC.

In addition to the proposed changes to the aquatic life criteria described above, the Department proposes spelling corrections or completion of missing chemical abstract service numbers for several pollutants.

3. Numeric Criteria Not Proposed for Adoption

a. EPA's Recommended Aluminum Criteria

The Department does not propose adopting the EPA's recommended acute and chronic aquatic life criteria for aluminum as a replacement of the current hardness-based water quality standard. In 2018, EPA published updated aquatic life criteria for aluminum, based on a multiple linear regression ("MLR") model that takes into account the effects of ambient water quality on the bioavailability of aluminum to freshwater aquatic life (**EXHIBIT 42**). The MLR is based on the observed interactions of aluminum, pH, hardness, and dissolved organic carbon ("DOC") in a compilation of toxicity tests consisting of *P. promelas* and *C. dubia*. The EPA found these three parameters have the most significant influence on the toxicity of aluminum. Development of the MLR model included a range of water quality conditions to capture the variability of ambient conditions: pH (6.0-8.7), hardness (9.8 to 428 mg/L), and DOC (0.08 to 12.3 mg/L). The EPA extrapolated the model to expand its applicability but cautions against using the MLR model for conditions outside the range of empirical testing, for pH in particular. The Department has concerns regarding EPA's linear regression extension of the model for pH ranges 5.0 to 6.0 and 8.7 to 10.5. Also of concern, the EPA MLR model guidance acknowledges temperature as a factor in aluminum solubility yet does not include temperature in the MLR model or explain why it did not use temperature.

Although the aluminum MLR model represents the best available science for calculating appropriate aluminum instantaneous water quality criteria ("IWQC") for freshwater aquatic life, the Department proposes retaining the current hardness-based standard. The Department cannot implement the MLR model effectively since the Department does not have a way to determine the MLR model input value of DOC with confidence. The New Mexico Department of Health Scientific Laboratory Division ("SLD") does not currently perform DOC analysis. SLD is building capacity for DOC analysis; however, the Department is uncertain of the implementation date. The Department has considered contract labs for DOC analysis but does not have the resources required for collection at every site. Recognizing that not all states or tribes can collect all required input parameters to the MLR model, the EPA implementation guidance (**EXHIBIT 43**) suggests using either default or ecoregional values for missing site-specific parameters. However, EPA cautions that the approach may be too general for areas of complex geology. The Department considers New Mexico geologically diverse. Default or ecoregional DOC values are unlikely to capture variability across the state or at a specific location under different flow conditions. The EPA provides ecoregional DOC values in its Draft Technical Support Document: Recommended Estimates for Missing Water Quality Parameters for Application in EPA's Biotic Ligand Model (Table 18, **EXHIBIT 44**) based on DOC results from EPA's National Rivers and Streams Assessment. However, the dataset for New Mexico consists of single site visits to relatively few waterbodies. For example, the entire eight-digit Hydrologic Unit Code ("HUC") representing the Pecos Headwaters watershed (13060001) contains four data points from 2008-2014 representing two ecoregions. The dataset does not represent many other areas of the state.

The Department compared criteria calculated from the MLR model and New Mexico's current hardness-based criteria (**EXHIBIT 45**). Overall, the MLR model results are more conservative (criteria are lower) within the range of DOC values expected for New Mexico's surface waters. At very low hardness, approximately 50 mg/L or less, both the chronic and acute hardness-based criteria are lower than those from the MLR model. The Department completed an analysis of the difference between the current hardness-based criteria and the MRL model criteria for total recoverable aluminum results collected during the 2017-2018 Upper Rio Grande watershed survey. The Department divided each total recoverable aluminum result by the IWQC calculated from the required input parameters, resulting in an exceedance ratio for each sample. The Department used a DOC concentration of 0.7 mg/L, the average of the recommended DOC concentrations for Omernik Level III ecoregions 21 and 22, for the MLR model input value. Exceedance ratios greater than one indicate a sampling result higher than the applicable IWQC. **EXHIBIT 46** graphs the difference between the MLR model exceedance ratio and the hardness-based exceedance ratio. Values greater than zero indicate the MLR model criterion is more stringent than the hardness-based criterion. These results confirm that hardness-based criteria are more stringent than those of the MLR model at lower hardness concentrations. The largest exceedance ratio differences between the hardness-based calculation and MLR model also occur at low hardness. This analysis identified 42 acute and 111 chronic exceedances using the hardness-based calculation, and 59 acute and 110 chronic exceedances using the MLR model. Overall, the hardness-based calculation resulted in more exceedances at lower hardness values and the MLR model resulted in more exceedances at higher hardness values (**EXHIBIT 47**).

The implementation of the 2018 EPA aluminum ambient water quality criteria ("AWQC") is further complicated because the guidance does not address the distinction between the bioavailable species of aluminum and those forms that are geologically based and present in natural waters as suspended sediment. The EPA acknowledges this challenge in its Final Aquatic

Life Ambient Water Quality Criteria for Aluminum 2018 guidance (**EXHIBIT 42**): "…natural water samples may also contain other species of aluminum that are not biologically available (i.e., suspended particles, clays, and aluminosilicate minerals)…This creates uncertainty because the total recoverable aluminum concentrations measured in natural waters may overestimate the potential risks of toxicity to aquatic organisms." Further, the EPA states that new analytical methods are needed, and it expects ongoing research to improve accurate measurement of toxic aluminum. For total recoverable aluminum analyses, the Department currently filters high turbidity samples with a 10-micron filter to remove terrestrial sediment. However, the infiltration of clay and some silt can still occur since these particles may pass through the filter. Adopting the MLR model may require refinement of this process to better discriminate bioavailable aluminum to prevent unnecessary, and potentially costly, impairment listings in high turbidity areas.

The Department concludes that it does not have adequate information to implement the 2018 aluminum aquatic life criteria with confidence. The Department will continue to evaluate the adoption of the revised aluminum criteria and expects to begin sampling and analysis of DOC. The Department estimates an annual cost of 8,500 Work-Time Units ("WTUs") per year for DOC, which is approximately 5% of SWQB's fixed annual budget with SLD. This extra cost reduces the amount the Department can allocate to sampling for other pollutants. Costs may also increase for NPDES permittees to account for additional monitoring.

b. EPA Section 304(a) Arsenic Criteria

The Department does not propose the adoption of the 2002 EPA recommended human health criterion for arsenic. The State documented the reasoning behind the current human health-organism only criterion of 9.0 µg/L in the Statement of Reason from the 2005 Triennial Review (**EXHIBIT 48**). The State adopted a New Mexico-specific criterion using arsenic water column and fish tissue concentration from the Rio Grande. The Department's analysis of surface water quality results for arsenic shows that undeveloped areas in New Mexico frequently exceed the EPA recommended concentration of 1.4 µg/L (increased by one order of magnitude to account for New Mexico's lifetime risk of more than one cancer per 100,000 exposed persons (20.6.2 NMAC)) (**EXHIBIT 49**). Since human health-organism only criteria cannot be modified for natural background (20.6.4.10(E) NMAC), adopting the more stringent criterion is not practicable.

c. EPA Section 304(a) Copper Criteria

The Department does not propose adopting the EPA's recommended aquatic life criteria for copper as a replacement of the current hardness-based water quality standard. In 2007, EPA introduced revised AWQC for copper using the Biotic Ligand Model ("BLM") (**EXHIBIT 50**) to take into account the various effects of ambient water quality on the toxicity of copper. Although the BLM provides a more accurate assessment of copper bioavailability than New Mexico's hardness-based criteria calculation, it requires the input of 11 coincident water quality parameters (some of which are not commonly available) for the calculation of an instantaneous water quality criterion. Recognizing the scarcity of data as a limitation of the BLM in its implementation guidance, the EPA recommends adopting the BLM for copper on a targeted basis while retaining hardness-based standards for all other waters (**EXHIBIT 51**). During the 2010 Triennial Review, the Commission adopted the provision described in 20.6.4.10(D)(4)(c) NMAC adding the BLM for copper as a scientifically defensible method for site-specific criteria development. The Department will continue to evaluate the implementation of the BLM for copper on a segment-specific basis.

d. EPA Section 304(a) Manganese Criteria

The Department does not propose the adoption of EPA's recommended water quality human health-organism only criterion for Manganese of 100 µg/L for human health. Manganese is a naturally occurring element commonly found in food and water and is a micronutrient required for cellular function. The EPA based its recommended human health criterion on manganese's organoleptic effects, including objectionable taste and laundry staining.

For application in New Mexico, as defined in 20.6.4.7(H)(2) NMAC, human health-organism only "means the health of humans who ingest fish or other organisms from waters that contain pollutants". Since the EPA criterion does not meet the definition of protecting human health, the Department does not support its adoption. Although there are numerous pollutants listed in 20.6.4.900(J)(1) NMAC with accompanying recommended organoleptic criteria in EPA's National Recommended Water Quality Criteria – Organoleptics (**EXHIBIT 52),** New Mexico has not adopted any numeric organoleptic criteria. However, the State does have a narrative criterion, provided in 20.6.4.13(D) NMAC, which protects against degradation of organoleptic quality from other than natural causes.

e. EPA Section 304(a) Selenium Criteria

In 2016, the EPA published a revised selenium criterion for freshwater aquatic life, available at https://www.epa.gov/wqc/final-aquatic-life-ambient-water-quality-criterion-selenium-freshwater-2016. Selenium is a naturally occurring element that is found usually in sedimentary rocks with high organic content, including coal-containing strata, and the soils derived from this lithology. Selenium also occurs in mineralized areas and is found in ores of copper, lead, and zinc. Deleterious concentrations of selenium in water may result from mining, petroleum extraction, or erosion of soils. Selenium bioaccumulates through the food web, primarily through assimilation of dissolved selenium by microorganisms followed by particulate matter ingestion. According to the EPA's recommended criteria, selenium's most sensitive adverse effects are found in the reproductive effects in fish and are the basis for the updated chronic criterion. Due to the significant chronic effects, EPA did not develop an acute criterion for selenium. EPA's recommended chronic criterion consists of two media, fish tissue and water concentration. An exceedance in either medium is considered an excursion above the criterion.

The criterion expresses fish tissue concentration as either egg/ovary or fish whole body/muscle, and in either case, the criterion element is an instantaneous value not to exceed.

The water concentration element is a thirty-day average exposure value for rivers/streams and lakes (1.5 µg/L and 3.1 µg/L, respectively) to not exceed more than once in three years. In its guidance, the EPA also provides a formula for calculating allowable intermittent water concentration excursions above background during a thirty-day period.

Although the EPA published the updated selenium criterion in 2016, it has not provided implementation guidance to states or tribes. Given the complexity of implementation and the absence of implementation guidance from the EPA, the Department is reluctant to invest already constricted resources for collecting fish tissue or 30 consecutive daily waterbody samples for assessing a single site. Additional guidance is needed to translate the criterion to alternative assessment periods. The Department will further evaluate the revised selenium criterion once the EPA finalizes implementation guidance. Until that time, the Department proposes retaining the current total recoverable selenium criterion for aquatic life of 5.0 µg/L chronic and 20.0 µg/L acute.

V. SPELLING AND FORMATTING AMENDMENTS

A. Removal of Redundant Dash (multiple citations)

The Department proposes removing dashes following colons in the basin description for 97 classified sections in 20.6.4.100-899 NMAC. Removal of the dash is consistent with formatting throughout NMAC. According to State Records Center and Archives (**EXHIBIT 53**), the correct formatting includes the section name in all capital letters followed by a colon then two spaces. The State Record Center and Archives has clarified that grammatical corrections such as these do not require an amendment notation for the section (**NMED Exhibit 54**); therefore, the proposed amendment will not add an amendment notation.

B. Correction of Spelling "Canyon Largo" in 20.6.4.405 and 20.6.4.408 NMAC

The Department proposes to amend 20.6.4.405 and 20.6.4.408 NMAC to correct the spelling of "Canyon Largo" to "Cañon Largo" to be consistent with accepted geographical references for the waterbody. The United States Geological Survey ("USGS") 7.5-minute topographical map, Google Earth, and the Department's Surface Water Quality Information Database ("SQUID") all identify the waterbody as Cañon Largo (**EXHIBIT 55**). Amending the language to be consistent with common reference is critical for water quality standards implementation.

C. Removal of Hanging Period in 20.6.4.808 NMAC

The Department proposes removing a mistakenly placed period between the words "to" and "the" in the third line of the description for Section 20.6.4.808 NMAC. The State Record Center and Archives has clarified that grammatical corrections such as these do not require an amendment notation for the section (**NMED Exhibit 54**); therefore, the proposed amendment will not add an amendment notation.

VI. CONCLUSION

The Department recommends that the Commission adopt the proposed amendments to the Standards, filed as **NMED Exhibit 9**, based upon the testimony of the SWQB's witnesses.

This concludes my direct testimony.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 4
ATLANTA FEDERAL CENTER
61 FORSYTH STREET
ATLANTA, GEORGIA 30303-8960

AUG 16 2016

James A. (Jac) Capp
Chief
Watershed Protection Branch
Environmental Protection Division
Georgia Department of Natural Resources
2 Martin Luther King Jr. Drive
Suite 1152 East
Atlanta, Georgia 30334

Dear Mr. Capp:

The United States Environmental Protection Agency has completed its review of amendments to Chapter 391-3-6-.03 of Georgia's Rules and Regulations for Water Quality Control. The revisions were adopted as a result of Georgia Environmental Protection Division's (GAEPD) triennial review of water quality standards (WQS), as required under the provisions of Clean Water Act (CWA or the Act) Section 303(c). GAEPD held six public meetings from February 6, 2013 until December 4, 2014, regarding development of these revised water quality criteria. The proposed revisions were publically noticed on EPD's website on May 8, 2015, and the public comment period ran through June 26, 2015. The State held public hearings on the proposed revisions on June 26, 2015. The revisions were adopted by the Board of Natural Resources on August 26, 2015, and became effective October 22, 2015. GAEPD submitted new and revised WQS to the EPA by letter dated March 22, 2016, which was received by the EPA on March 29, 2016. GAEPD's submittal included a certification letter dated February 23, 2016, signed by Samuel Olens, Georgia Attorney General, which stated that the revisions were duly adopted in accordance with State law.

As laid out in the enclosed decision document, titled *Decision Document of the United States Environmental Protection Agency Review of Amendments to Georgia's Water Quality Regulations at Chapters 391-3-6-.03 and 391-3-6-.06 Under § 303(c) of the Clean Water Act,* the EPA is approving all new and revised WQS as documented in 391-3-6-.03 and 391-3-6-.06(4). These revisions include amendments to designate a section of the Conasauga River as an Outstanding National Resource Water, to describe Tier 3 antidegradation requirements, to adopt a site specific copper criteria for Buffalo Creek, to revise bacterial criteria for recreational waters, to update specific water use classifications of various waterbodies, to remove a footnote referencing the streamflow at which specific criteria apply in the Chattahoochee River from Atlanta (Peachtree Creek) to Cedar Creek, to clarify the definition of total lake loading of phosphorus, and to remove a variance to the narrative toxicity standard on Cabin Creek.

In addition to our review pursuant to Section 303 of the Clean Water Act, Section 7(a)(2) of the Endangered Species Act requires federal agencies, in consultation with the U.S. Fish and Wildlife Service (FWS) (and National Marine Fisheries Service where applicable), to ensure that their actions are not likely to jeopardize the continued existence of federally listed species or result in the destruction or adverse modification of designated critical habitat of such species. On June 16, 2016, FWS concurred with the EPA's determination that the revisions to Georgia's Water Quality Regulations contained in Chapter 391-3-6-.03 either have no effect or may affect, but are unlikely to adversely affect listed species or habitat. The EPA's concurrence letter can be found in Appendix B of the decision document.

We would like to commend you and your staff for your continued efforts to protect and enhance Georgia's waters during this rulemaking. We appreciate Georgia's efforts throughout the WQS development process. If you have questions regarding this action by the EPA, please contact me at (404) 562-9345 or have a member of your staff contact Mr. Jason Poe (404) 562-9827.

Sincerely,

James D. Giattina
Director
Water Protection Division

Enclosure

cc: Elizabeth Booth, GAEPD

Decision Document of the United States Environmental Protection Agency Review of Amendments to Georgia's Water Quality Regulations at Chapters 391-3-6-.03 and 391-3-6-.06 under § 303(c) of the Clean Water Act

This document summarizes the EPA review of the revisions to Water Quality Regulations at Chapters 391-3-6-.03 and 391-3-6-.06 adopted by the State of Georgia. These revisions were adopted as a result of Georgia's water quality standards rulemaking. The state submitted the water quality standards (WQS) revisions by letter dated March 22, 2016, from James A. Capp, Georgia Environmental Protection Division, Watershed Protection Branch Chief, to James D. Giattina, Director, Water Protection Division, Environmental Protection Agency, Region 4. The EPA received the revisions on March 29, 2016. The submittal to the EPA was accompanied by certification from Samuel Olens, Georgia Attorney General, dated February 23, 2016, that the standards revisions were duly adopted pursuant to the state law of Georgia. The public comment period for the rulemaking began on May 8, 2015, and ended on June 26, 2015, and a public hearing was held on June 26, 2015. In response to the public comments received, the state prepared a Response to Comments dated August 6, 2015. The revisions were adopted by the Board of Natural Resources on August 26, 2015, and became effective October 22, 2015.

Additions to the State's WQS regulations are shown underlined below, while deletions to the regulations are shown with strikethrough. As discussed more fully below, where the EPA has determined that the State's rule revisions are themselves new or revised WQS, the EPA has reviewed and acted on these revisions pursuant to Section 303(c) of the Clean Water Act (CWA).[1] Section 303 of the CWA, 33 U.S.C. § 1313, requires states to establish WQS and to submit any new or revised standards to the EPA for review and approval or disapproval. The EPA's implementing regulations require states to adopt water quality criteria that protect the designated use. See 40 C.F.R. § 131.11(a). Such criteria must be based on a sound scientific rationale, and must contain sufficient parameters or constituents to protect the designated use. For waters with multiple use designations, the criteria shall support the most sensitive use. In addition, the EPA's regulations require that in establishing criteria, a state shall consider WQS of downstream waters and shall ensure that its WQS provide for the attainment and maintenance of WQS of downstream waters. See 40 C.F.R. § 131.10(b).

A state's submission of water quality criteria must include (1) the methods used and analyses conducted to support water quality standards revisions, (2) water quality criteria sufficient to protect the designated uses and (3) a certification by the State Attorney General or other appropriate legal authority within the state that the WQS were duly adopted pursuant to state law. See 40 C.F.R. § 131.6.

Based on the review of the State's submittal, the EPA has determined that the new and revised standards listed below are consistent with 40 C.F.R. Part 131 and Section 303 of the CWA. Therefore, the EPA is approving the following new and revised WQS:

- Revisions of Rule 391-3-6-.03(2) to designate a section of the Conasauga River as an Outstanding National Resource Water and to describe Tier 3 antidegradation requirements.
- Revisions of Rule 391-3-6-.03(5) to adopt a site specific copper criteria for Buffalo Creek.
- Revisions of Rule 391-3-6-.03(6) to revise bacterial criteria for recreational waters.

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[1] The EPA has provided FAQs on "What is a New or Revised Water Quality Standard Under CWA 303(c)(3)?" at http://water.epa.gov/scitech/swguidance/standards/cwa303faq.cfm. The link provides detailed information of such analysis.

- Revisions of Rule 391-3-6-.03(14) to update specific water use classifications of various waterbodies and to remove a footnote referencing the streamflow at which specific criteria apply in the Chattahoochee River from Atlanta (Peachtree Creek) to Cedar Creek.
- Revisions of Rule 391-3-6-.03(17) to clarify the definition of total lake loading of phosphorus.
- Revisions of Rule 391-3-6-.06(4) to remove a variance to the narrative toxicity standard on Cabin Creek.

New and Revised Standards that are Approved by the EPA:

The State adopted the following revisions, which are shown in underline (new provisions) and strikethrough (deleted provisions):

Revisions of Rule 391-3-6-.03(2) to designate a section of the Conasauga River as an Outstanding National Resource Water and to describe Tier 3 antidegradation requirements.

(a) The purposes and intent of the State in establishing Water Quality Standards are to provide enhancement of water quality and prevention of pollution; to protect the public health or welfare in accordance with the public interest for drinking water supplies, conservation of fish, wildlife and other beneficial aquatic life, and agricultural, industrial, recreational, and other reasonable and necessary uses and to maintain and improve the biological integrity of the waters of the State.
(b)~~(i) Existing instream water uses and the level of water quality necessary to protect the existing uses shall be maintained and protected.~~ The following paragraphs describe the three tiers of the State's waters.
(i) Tier 1 - Existing instream water uses and the level of water quality necessary to protect the existing uses shall be maintained and protected.
(ii) Tier 2 - Where the quality of the waters exceed levels necessary to support propagation of fish, shellfish, and wildlife and recreation in and on the water, that quality shall be maintained and protected unless the division finds, after full satisfaction of the intergovernmental coordination and public participation provisions of the division's continuing planning process, that allowing lower water quality is necessary to accommodate important economic or social development in the area in which the waters are located. In allowing such degradation or lower water quality, the division shall assure water quality adequate to protect existing uses fully. Further, the division shall assure that there shall be achieved the highest statutory and regulatory requirements for all new and existing point sources and all cost-effective and reasonable best management practices for nonpoint source control.
~~(c)~~(iii) Tier 3 - Outstanding National Resource Waters (ONRW). This designation will be considered for an outstanding national resource waters, such as waters of National or State parks and wildlife refuges and waters of exceptional aesthetic, historic, recreational, or ecological significance. For waters designated as ONRW, existing water quality shall be maintained and protected. The following waters below are designated as ONRWs: Conasauga River within the Cohutta Wilderness Area of the Chattahoochee National Forest (headwaters to Forest Service Road 17).

4. Activities that result in short-term, temporary, and limited changes to water quality may be allowed if authorized by the Division and the water quality is returned or restored to conditions equal to or better than those existing prior to the activities.

The state antidegradation policy is being revised to clarify the three antidegradation Tiers – specifically to include consideration of aesthetic and historic significance attributes when designating Outstanding National Resource Waters (ONRW) and to add language that activities that result in short-term, temporary, and limited changes to water quality may be allowed if authorized by the Division. This is consistent with 40 C.F.R. § 131.12(a)(3), which states that, "Where high quality waters constitute an outstanding National resource, such as waters of National and State parks and wildlife refuges and waters of exceptional recreational or ecological significance, that water quality shall be maintained and protected." It is also consistent with Water Quality Standards Regulation preamble that, "States may allow some limited activities which result in temporary and short-term changes in water quality…" [2]With this action the State also added the Conasauga River as an ONRW.

The revisions also designate the Conasauga River in the Cohutta Wilderness Area as Georgia's first ONRW. The Conasauga River headwaters were first nominated for ONRW status in 2007 by the Environment Georgia Research and Policy Center. GAEPD worked with stakeholders to update the 2004 Procedures for Selection of Outstanding National Resource Waters, completing revisions in 2011. On June 22, 2012, the Environment Georgia Research and Policy Center submitted a complete nomination package which included waterbody characteristics, a mapped delineation, reasons for nomination, a stakeholder inventory, control and enforcement documentation, nominating groups, a cost benefits analysis, documentation of public involvement, landuse/landcover information, and a watershed inventory. The designation applies to an eleven-mile reach of the Conasauga River within the Cohutta Wilderness Area of the Chattahoochee National Forest (headwaters to Forest Service Road 17). The nomination package documents high existing water quality and ecological value, exceptional recreational or aesthetic value, and strong community support for ONRW designation. The designation therefore is consistent with the requirements of 40 C.F.R. § 131.12(a)(3), ensuring the maintenance and protection of the Conasauga's exceptional recreational or ecological significance.

Revisions of Rule 391-3-6-.03(5) to adopt a site specific copper criteria for Buffalo Creek.

(e)(ii) Site-specific Copper criteria developed using the biotic ligand model (BLM): Buffalo Creek (Richards Lake Dam to confluence with Little Tallapoosa River):

$$\text{Acute criteria} = 4.9X10^8 \; e^{\left(-0.5\left(\left(\frac{\ln(pH)-2.316}{-0.1816}\right)^2+\left(\frac{\ln(DOC)-32.18}{-5.453}\right)^2\right)\right)}$$

$$\text{Chronic criteria} = 3.043X10^8 \; e^{\left(-0.5\left(\left(\frac{\ln(pH)-2.316}{-0.1816}\right)^2+\left(\frac{\ln(DOC)-32.18}{-5.453}\right)^2\right)\right)}$$

The State revision of copper criteria adds site-specific criteria for Buffalo Creek, from Richards Lake Dam to confluence with Little Tallapoosa River. The criteria were developed using the Biotic Ligand Model (BLM) to determine metal toxicity correcting for bioavailability based on waterbody chemistry. Acute and chronic criteria were developed to protect against immediate effects, such as mortality, and long term effects, such as reproduction, growth and survival. The BLM uses ten water chemistry

[2] Federal Register Volume 48, Number 217, Tuesday, November 8, 1983

parameters to calculate a freshwater copper criterion, but studies indicated that the bioavailability of copper in Buffalo Creek is primarily dependent on the instream pH and Dissolved Organic Carbon (DOC), so the site-specific copper criteria are expressed as equations based on instream pH and DOC concentrations. The criteria were developed following EPA's Aquatic Life Ambient Freshwater Quality Criteria for Copper, February 2007 (EPA-822-R-07-001), are protective of the designated uses for this stream segment and are consistent with the CWA and 40 C.F.R. Part 131.

Revisions of Rule 391-3-6-.03(6) and 391-3-6-.03(12) to revise bacterial criteria for recreational waters.

(6)(a)(i) Bacteria: For the months of May through October, when water contact recreation activities are expected to occur, fecal coliform not to exceed a geometric mean of 200 per 100 mL based on at least four samples collected from a given sampling site over a 30-day period at intervals not less than 24 hours. Should water quality and sanitary studies show fecal coliform levels from non-human sources exceed 200/100 mL (geometric mean) occasionally, then the allowable geometric mean fecal coliform shall not exceed 300 per 100 mL in lakes and reservoirs and 500 per 100 mL in free flowing freshwater streams. For the months of November through April, fecal coliform not to exceed a geometric mean of 1,000 per 100 mL based on at least four samples collected from a given sampling site over a 30-day period at intervals not less than 24 hours and not to exceed a maximum of 4,000 per 100 mL for any sample. The State does not encourage swimming in these surface waters since a number of factors which are beyond the control of any State regulatory agency contribute to elevated levels of fecal ~~coliform~~bacteria.
(b)(i) Bacteria: ~~Fecal coliform not to exceed the following geometric means based on at least four samples collected from a given sampling site over a 30-day period at intervals not less than 24 hours:~~
1. Coastal waters ~~100 per 100 mL:~~ Culturable enterococci not to exceed a geometric mean of 35 CFU (colony forming units) per 100 mL. The geometric mean duration shall not be greater than 30 days. There shall be no greater than a ten percent excursion frequency of an enterococci statistical threshold value (STV) of 130 CFU per 100 mL in the same 30-day interval.
2. All other recreational waters ~~200 per 100 mL:~~ Culturable E. coli not to exceed a geometric mean of 126 CFU (colony forming units) per 100 mL. The geometric mean duration shall not be greater than 30 days. There shall be no greater than a ten percent excursion frequency of an E. coli statistical threshold value (STV) of 410 CFU per 100 mL in the same 30-day interval.
~~3. Should water quality and sanitary studies show natural fecal coliform levels exceed 200/100 mL (geometric mean) occasionally in high quality recreational waters, then the allowable geometric mean fecal coliform level shall not exceed 300 per 100 mL in lakes and reservoirs and 500 per 100 mL in free flowing fresh water streams~~
(c)(iii) Bacteria: 1. For the months of May through October, when water contact recreation activities are expected to occur, fecal coliform not to exceed a geometric mean of 200 per 100 mL based on at least four samples collected from a given sampling site over a 30-day period at intervals not less than 24 hours. Should water quality and sanitary studies show fecal coliform levels from non-human sources exceed 200/100 mL (geometric mean) occasionally, then the allowable geometric mean fecal coliform shall

not exceed 300 per 100 mL in lakes and reservoirs and 500 per 100 mL in free flowing freshwater streams. For the months of November through April, fecal coliform not to exceed a geometric mean of 1,000 per 100 mL based on at least four samples collected from a given sampling site over a 30-day period at intervals not less than 24 hours and not to exceed a maximum of 4,000 per 100 mL for any sample. The State does not encourage swimming in these surface waters since a number of factors which are beyond the control of any State regulatory agency contribute to elevated levels of ~~fecal coliform~~bacteria.

(12) ~~Fecal Coliform~~Bacteria Criteria. The criteria for ~~fecal coliform~~ bacteria provide the regulatory framework to support the USEPA requirement that States protect all waters for ~~the use of primary contact~~ recreational use ~~or swimming~~. The bacterial indicators for primary contact recreational waters are E. coli and enterococci. The bacterial indicator for secondary contact recreational waters is fecal coliform. ~~This is a worthy national goal, although potentially unrealistic with the current indicator organism, fecal coliform bacteria, in use today. To assure that waters are safe for swimming indicates a need to test waters for pathogenic bacteria. However, analyses for pathogenic bacteria are expensive and results are generally difficult to reproduce quantitatively. Also, to ensure the water is safe for swimming would require a whole suite of tests be done for organisms such as Salmonella, Shigella, Vibrio, etc. as the presence/absence of one organism would not document the presence/absence of another. This type of testing program is not possible due to resource constraints. The environmental community in the United States has based the assessment of the bacteriological quality of water on testing for pathogenic indicator organisms, principally on the coliform group. The assessment of streams, rivers, lakes, and estuaries in Georgia and other States is based on fecal coliform organisms.~~
(a) Fecal c~~C~~oliform, E. coli and enterococci bacteria live in the intestinal tract of warm blooded animals including man. These organisms are excreted in extremely high numbers~~, averaging about 1.5 billion coliform per ounce of human feces~~. Pathogenic bacteria also originate in the fecal material of diseased persons. Therefore, waters with high levels of ~~fecal coliform~~ bacteria represent potential problem areas for swimming. Scientific studies indicate there is a positive correlation between E. coli and enterococci counts and gastrointestional illness. However, there is no positive scientific evidence correlating elevated fecal coliform counts with transmission of enteric diseases. In addition, these bacteria can originate from any warm blooded animal or from the soil.
(b) Monitoring programs have documented ~~fecal coliform~~bacterial levels in excess of the criteria in many streams and rivers in urban areas, agricultural areas, and even in areas not extensively impacted by man such as national forest areas. This is not a unique situation to Georgia as similar levels of fecal coliform bacteria have been documented in streams across the nation. ~~The problem appears to lie in the lack of an organism which specifically indicates the presence of human waste materials which can be correlated to human illness. Other organisms such as the Enterococci group and E. coli have been suggested by the USEPA as indicator organisms. However, testing using these organisms by States and the USEPA has indicated similar problems with these indicator organisms.~~
~~(c) The Environmental Protection Division will continue to conduct monitoring to evaluate the use of E. coli and Enterococci as indicators of bacteriological quality in~~

~~Georgia. The Environmental Protection Division will also conduct studies to determine if a better human specific indicator can be found to replace current indicator organisms.~~

The State revisions adopt bacteria criteria for waters designated as Recreation, based on EPA's 2012 Recreational Bacteria Criteria recommendations. Epidemiological studies determined that E. coli and enterococci are better indicators of gastrointestinal illness than fecal coliform. The criteria were adopted corresponding with EPA's Recreational Water Quality Criteria, November 2012, (EPA-820-F-12-058), are protective of the recreational use and are consistent with the CWA and 40 C.F.R. Part 131.

The State revised Rule 391-3-6-.03(14) to update specific water use classifications of various waterbodies.

All littoral waters on the ocean side of ~~St. Simons,~~ Sea~~,~~ and Sapelo Islands, and on the ocean and sound side of St. Simons Island		Recreation
Buttermilk Sound	Reimolds Pasture	Recreation
Chattahoochee River	Atlanta (Peachtree Creek) to Cedar Creek	Fishing~~[1]~~
Headwaters of Unnamed Tributary to Bethlehem Creek	Bethlehem Creek to Lake Franklin, F.D. Roosevelt State Park Beaches	Recreation
Little Kolomoki Creek	Lake Kolomoki, Kolomoki Mounds State Park Beach	Recreation
Smith Creek	Unicoi Lake, Unicoi State Park Beach	Recreation
Headwaters of Gold Mine Branch	Fort Mountain Lake, Fort Mountain State Park Beach	Recreation
Tributaries to Heath Creek	Rocky Mountain Public Fishing Lakes, Rocky Mountain Public Fishing Area	Recreation
Flint River	Georgia Hwy. 27 to Georgia Power Dam at Lake Worth, Albany including Lakes Blackshear, Chehaw, and Worth	Recreation

Little River	Reed Bingham State Park Lake, Reed Bingham State Park Lake Beach	Recreation
Big Sandy Creek	Chief McIntosh Lake, Indian Springs State Park Beaches	Recreation
Headwaters of Little Ocmulgee River	Little Ocmulgee Lake, Little Ocmulgee State Park Beach	Recreation
Towaliga River	High Falls Lake, High Falls State Park Beaches	Recreation
Hard Labor Creek	Lake Rutledge, Hard Labor Creek State Park Beaches	Recreation
Marbury Creek	Fort Yargo Lake, Fort Yargo State Park Beaches	Recreation
Julienton River	Contentment Bluff Sandbar and Dallas Bluff Sandbar	Recreation
Skidaway River	Skidaway Narrows in Chatham County	Recreation
All littoral waters on the ocean side of Cumberland ~~and Jekyll~~ Island~~s~~		Recreation
All littoral waters on the ocean and sound side of Jekyll Island		Recreation
South Brunswick River	Blythe Island Sandbar	Recreation
Unnamed Tributary to Lick Creek	Lake Liberty, A.H. Stephens State Park Beach	Recreation
Big Creek	Lake Laura S. Walker, Laura Walker State Park Beach	Recreation
Wolf Creek	Lake Trahlyta, Vogel State Park Beach	Recreation

The State's action to add the Recreation use to these segments recognizes current use of these waters for general recreational activities, such as water skiing, boating, and swimming. Due to the provisions of 391-3-6-.03(6)(b) that uses for the Recreation use include "[g]eneral recreational activities such as water skiing, boating, and swimming, or for any other use requiring water of a lower water quality", the assignment of the Recreation use also incorporates protective criteria for the aquatic life uses of the Fishing use. Therefore, the assignment of the Recreation use for these segments provides for the protection of the CWA Section 101(a) use goals and is consistent with 40 C.F.R. Part 131.

The State revised Rule 391-3-6-.03(14) to remove a footnote referencing the streamflow at which specific criteria apply in the Chattahoochee River from Atlanta (Peachtree Creek) to Cedar Creek.

The State revisions remove the footnote to Specific Water Use Classifications at 391-3-6-.03(14) for the Chattahoochee River Atlanta (Peachtree Creek) to Cedar Creek, which states that, "Specific criteria apply at all times when the river flow measured at a point immediately upstream from Peachtree Creek equals or exceeds 750 cfs (Atlanta gage flow minus Atlanta water supply withdrawal)." The use classification for this section of the River and the associated footnote were approved by the EPA on August 18, 1975, to upgrade the use classification and associated water quality criteria from Industrial to Fishing for all flows above 750 cubic feet per second or cfs. At that time, the State could not ensure that the WQS could be met below 750 cfs due to significant amounts of industrial pollution in the River. With the footnote in place, exceedances of WQS were not considered an exceedance under the CWA if the flow of the River was below 750 cfs. With this revision to remove the footnote, the use designation of Fishing and all associated WQS now apply.

The Fishing designated use as described in Rule 391-3-6-.03(6)(c) includes the "Propagation of Fish, Shellfish, Game and Other Aquatic Life; secondary contact recreation[3] in and on the water; or for any other use requiring water of a lower quality". The EPA notes that pursuant to Rule 391-3-6.03(9), with the removal of the footnote the specific criteria for the Fishing designated use now apply at all flows, including dissolved oxygen, temperature, pH, and bacteria. General criteria, such as narratives, metals, pesticides and organic compounds, now apply to the River in the same manner as to all other waters in the state. Therefore, with this change, the EPA recommends that the State re-evaluate the measured low flows and calculated critical low flows and ensure that they are properly used to apply all criteria in this section of the River. In 2014, the EPA updated the section on critical low flows in the Water Quality Standards Handbook noting the ongoing need for states and tribes to continually update this type of information (EPA WQS Handbook Chapter 5, See Section 5.2, pages 13-14.) For instance, the Handbook states that, "…prolonged droughts have resulted in a reduction of the low-flow minimums released on regulated rivers or revisions to drought control manuals to allow for further reductions of the low-flow values. …It may be prudent for states and tribes to review and revise, as appropriate, their critical low-flow values during the triennial review process to account for changes to historical flow patterns."

Once the new low flows are updated, the State should also re-evaluate monitoring, assessment, Total Maximum Daily Loads (TMDLs), and permitting on this segment of the Chattahoochee River to ensure that all uses are protected at all flows and that criteria will not be exceeded or uses be impaired should the River go below 750 cfs. The EPA appreciates EPD directly addressing its intention to do this in the public stakeholder meetings in December of 2014 (Appendix A). EPD stated, "…the 750 cfs was the

[3] "Secondary contact recreation" is incidental contact with the water, wading, and occasional swimming.

minimum flow used to develop wasteload allocations for dischargers to the Chattahoochee River downstream from Peachtree Creek…EPD intends to ensure that WQS are met at all flows."[5]

The EPA will continue to evaluate the Reasonable Potential Analyses (RPAs) contained in the National Pollutant Discharge Elimination System permits as they come in for reissuance to ensure that the appropriate critical conditions are used. The EPA is also ready to assist as needed with the review of any revisions to TMDLS. Should the measured or calculated flow values change, the permit limits based on those values would have to be re-evaluated as well as the threshold at which numeric nutrient criteria apply. The re-evaluation of critical low flows is important to ensure that all permit limits and TMDLs remain protective because the River has been operated with lower flows in the past. Some parameters are more readily measured and modeled, such as dissolved oxygen, yet EPD should ensure that all narrative and numeric criteria will be protected in addition to the implicit protection of the flows needed to meet designated uses. The EPA clarified the need to protect downstream uses and aquatic life, including any changes relating to either pollutants or pollution, such as hydrologic alteration, in its publication, Protection of Downstream Waters in Water Quality Standards: Frequently Asked Questions (EPA-820-F-14-001) as well as in the *Draft EPA-USGS Technical Report: Protecting Aquatic Life from Effects of Hydrologic Alteration* (EPA Report 822-P-15-002). The removal of the footnote completes the upgrade of this water to a full Fishing use, meeting the CWA Section 101(a)(2) uses, and ensures the protection of the designated use of the River segment at all flows. Therefore, the removal is consistent with the CWA and 40 C.F.R. Part 131.

Revisions of Rule 391-3-6-.03(17) to clarify the definition of total lake loading of phosphorus.

(17)(a)(iv) Total Phosphorous: Total lake loading shall not exceed 2.4 pounds per acre foot of lake volume per year.
(v) ~~Fecal Coliform~~ Bacteria:
1. U.S. 27 at Franklin to New River: Fecal coliform bacteria shall not exceed the Fishing criterion as presented in 391-3-6-.03(6)(c)(iii).
2. New River to West Point Dam: ~~Fecal coliform bacteria~~E. coli shall not exceed the Recreation criterion as presented in 391-3-6-.03(6)(b)(i).

(17)(b)(iv) Total Phosphorous: Total lake loading shall not exceed 2.4 pounds per acre-foot of lake volume per year.
(v) ~~Fecal Coliform~~Bacteria:
1. Georgia Highway 39 to Cowikee Creek: Fecal coliform bacteria shall not exceed the Fishing criterion as presented in 391-3-6-.03(6)(c)(iii).
2. Cowikee Creek to Walter F. George Dam: ~~Fecal coliform bacteria~~E. coli shall not exceed the Recreation criterion as presented in 391-3-6-.03(6)(b)(i).

(17)(c)(iv) Total Phosphorous: Total lake loading shall not exceed 5.5 pounds per acre-foot of lake volume per year.
(v) ~~Fecal Coliform~~Bacteria: ~~Fecal coliform bacteria~~E. coli shall not exceed the Recreation criterion as presented in 391-3-6-.03(6)(b)(i).

[5] GA EPD PowerPoint presentation at the first public stakeholder meeting, slide 31, December 2, 2014.

(17)(d)(iv) Total Phosphorous: Total lake loading shall not exceed 1.3 pounds per acre-foot of lake volume per year.
(v) ~~Fecal Coliform~~Bacteria:
1. Etowah River, State Highway 5 to State Highway 20: Fecal coliform bacteria shall not exceed the Fishing Criterion as presented in 391-3-6.--.03(6)(c)(iii).
2. Etowah River, State Highway 20 to Allatoona Dam: ~~Fecal coliform bacteria~~E. coli shall not exceed the Recreation criterion as presented in 391-3-6.--.03(6)(b)(i).

(17)(e)(iv) Total Phosphorous: Total lake loading shall not exceed 0.25 pounds per acre-foot of lake volume per year.
(v) ~~Fecal Coliform~~Bacteria: ~~Fecal coliform bacteria~~E. coli shall not exceed the Recreation criterion as presented in 391-3-6-.03(6)(b)(i).

(17)(f)(iv) Total Phosphorous: Total lake loading shall not exceed 172,500 pounds or 0.46 pounds per acre-foot of lake volume per year.
(v) ~~Fecal Coliform~~Bacteria: ~~Fecal coliform bacteria~~E. coli shall not exceed the Recreation criterion as presented in 391-3-6-.03(6)(b)(i).

The State action clarifies that loadings are of total phosphorus (versus elemental or other forms of phosphorus) and updates the bacterial indicator based on the revised bacteria criteria. These revisions ensure clarity and consistency in the standards and are consistent with the CWA and 40 C.F.R. Part 131.

Revisions of Rule 391-3-6-.06(4) to remove a variance to the narrative toxicity standard on Cabin Creek.

391-3-6-.06(4)(d)(5)(v)(d)(vii) Permits issued or reissued after the adoption of this paragraph may include site specific temporary exceptions to the applicable water quality standards under Chapter 391-3-6-.03(5)(e) when the requirements of this paragraph are met and the temporary exception is specifically authorized herein. Where a discharger cannot meet applicable limits for whole effluent toxicity because of a water quality based whole effluent toxicity criteria, site-specific temporary exceptions may be allowed on effluent dominated receiving streams under 7-day, 10-year minimum stream flow (7Q10) conditions provided that it has been demonstrated that the permitted discharge will comply with all chemical specific and other applicable water quality criteria, that the receiving stream will support a balanced indigenous population of aquatic life, and that controls more stringent than those required by Section 301(b) and 306 of the Federal Act for achieving whole effluent toxicity criteria would result in substantial and widespread adverse economic and social impacts to the affected communities. These site-specific exceptions shall be applicable only to the wastewater discharge as permitted at the time the exception is authorized with no changes in process or wastewater characteristics that would adversely affect water quality in the receiving stream or adversely affect the ability of potential new pollution abatement technologies to attain compliance with the whole effluent toxicity criteria. These site-specific exceptions shall be reviewed consistent with 40 CFR 131.20 at least once in every 3- year period. If it is determined that feasible new pollution abatement technologies or alternatives have become available to allow compliance with whole effluent toxicity criteria, these site-specific exceptions may be revoked and the NPDES permits modified to require implementation of such pollution abatement technologies or alternatives as soon as reasonably practicable. Along with this permit modification will be a requirement for the permittee to comply with the water quality based whole effluent toxicity criteria after installation of these technologies. ~~The following discharges and stream segments are hereby granted temporary exception from water quality standards for water quality based whole effluent toxicity criteria: Springs Industries Griffin Finishing Plant, NPDES Permit No. GA0003409, discharge to Cabin Creek in the Ocmulgee River Basin in Spalding County from the point of discharge downstream to Walkers Mill Road.~~

The State action removes a temporary exception from WQS for whole effluent toxicity criteria for the discharge to Cabin Creek in the Ocmulgee River Basin in Spalding County. This variance was adopted by Georgia in April 2000, and approved by EPA in January 2002 for the Spring Industries Griffin Finishing Plant discharge downstream to the Walkers Mill Road crossing in Cabin Creek in the Ocmulgee River Basin. The facility closed in December 2009 and the temporary exception from water quality standards is no longer needed. Its removal reinstates all criteria for this stream segment and is consistent with the CWA and 40 C.F.R. Part 131.

Review of Non-substantive Revisions to Water Quality Standards

The EPA determined that the changes within Rule 391-3-6-.03 listed below are editorial, non-substantive changes to Georgia's EPA-approved WQS. The EPA approves the editorial, non-substantive changes as being consistent with the CWA and the EPA's implementing regulations. The EPA notes, however, that its approvals of these editorial, non-substantive changes do not re-open the EPA's prior approvals of the underlying substantive WQS.

391-3-6-.03 "Water Use Classifications and Water Quality Standards.~~*~~"
~~*Applicable to Intrastate and Interstate Waters of Georgia.~~

(3)(i) "Naturally variable parameters." It is recognized that certain parameters including dissolved oxygen, pH, bacteria, turbidity and water temperature, vary through a given period of time (such as daily or seasonally) due to natural conditions. Assessment of State waters may allow for a 10% excursion frequency for these parameters.
This change addresses a water quality assessment process and is not a new or revised water quality standard.

(3)(m) "Significant Figures." The number of "~~S~~significant ~~F~~figures" represented in numeric criteria are the number of figures or digits that have meaning as estimated from the accuracy and precision with which the quantity was measured and the data were rounded off.
This change addresses a data quality issue and is not a new or revised water quality standard.

(5)(e)(i) 3. 2,4,5-Trichlorophenoxy propionic acid (TP Silvex) 50 μg/L ~~(TP Silvex)~~

(5)(e)(ii) [4] This pollutant is addressed in 391-3-6-.06. [4] ~~This pollutant is addressed in 391-3-6-.06.~~

Nickel
acute criteria = (e $^{(0.8460[\ln(\text{hardness})] + 2.255)}$)(0.998) µg/L
chronic criteria = (e $^{(0.8460[\ln(\text{hardness})] + 0.0584)}$))(0.997) µg/L
(5)(e)(iv)
11. Benzo(a)Pyrene (CAS RN[1] 50328) 0.018 µg/L
43. 3,3'-Dichlorobenzidine (CAS RN[1] 91941) 0.028 µg/L

(6)(i) Dissolved Oxygen ~~(D.O.)~~:

(7) Natural Water Quality. It is recognized that certain natural waters of the State may have a quality that will not be within the general or specific requirements contained herein. These circumstances do not constitute violations of WQS. This is especially the case for the criteria for dissolved oxygen, temperature, pH and ~~fecal coliform~~bacteria. NPDES permits and best management practices will be the primary mechanisms for ensuring that discharges will not create a harmful situation.

The EPA's action to approve new and revised standards is subject to completion of consultation under Section 7(a)(2) of the Endangered Species Act (ESA), 16 U.S.C. § 1536(a)(2). Based on review of available information, the EPA has determined that the Agency has "no discretion" in the approval of the revisions to the water quality criterion for revisions of Rule 391-3-6-.03(6) to revise bacterial criteria for recreational waters under ESA Section 7 based on the fact that the criterion are established for the protection of human health as an endpoint. Also, the EPA determined that the Agency has "no discretion" in the designation of the Conasauga River as an Outstanding National Resource Water and the revision of the State's antidegradation policy clarifying the three antidegradation tiers because the EPA is not authorized to require anything more than the requirements listed in 40 CFR. §131.12. The EPA prepared a Biological Evaluation (BE) in support of the Agency's approval of the new and revised WQS provisions, and this BE was provided to the U.S. Fish and Wildlife Service (FWS). In the BE, the EPA did note the presence of several federally-listed threatened and endangered species and designated critical habitat in the areas under consideration. The EPA determined the following revision was "may affect, not likely to adversely affect" federally listed species: to adopt a site specific copper criteria for Buffalo Creek. The EPA determined the following revisions would have "no effect" on federally-listed species: to update specific water use classifications of various waterbodies, to remove a footnote referencing the streamflow at which specific criteria apply in the Chattahoochee River from Atlanta (Peachtree Creek) to Cedar Creek, to clarify the definition of total lake loading of phosphorus, and to remove a variance to the narrative toxicity standard on Cabin Creek. In a letter dated June 17, 2016, Strant Colwell, Coastal Supervisor of Georgia Ecological Services, FWS, concurred with the EPA's determination that the WQS revisions were either "may affect, not likely to adversely affect" federally-listed species or would have "no effect" on federally-listed species (Appendix B).

Conclusion

Based on the reasons outlined above, the EPA concludes that the requirements of the CWA and 40 CFR §131 have been met for the new or revised WQS. The EPA approves the revised standards addressed in this Decision Document pursuant to Section 303(c) of the CWA.

8/15/16
Date

James D. Giattina
Director
Water Protection Division

Appendix A (GA EPD PowerPoint presentation at the first public stakeholder meeting, slide 31, December 2, 2014)

750 cfs Footnote

- Chattahoochee River, Atlanta (Peachtree Creek) to Cedar Creek footnote states that specific criteria apply at all times when the river flow upstream from Peachtree Creek equals or exceeds 750 cfs.
- Historically, the 750 cfs was the minimum flow used to develop wasteload allocations for dischargers to the Chattahoochee River downstream from Peachtree Creek.
- However, EPD intends to ensure that water quality standards are met at all flows.

Appendix B (FWS BE Concurrence Letter)

United States Department of the Interior

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June 17, 2016

Ms. Joanne Benante
U. S. Environmental Protection Agency
Water Quality Planning Branch
61 Forsyth Street
Atlanta, Georgia 30303-8960

Service File Number:	04EG1000-2016-CPA-0361
Service Consultation File Number:	04EG1000-2016-I-1277
Service Contaminant Activity Code:	04EG1000-2016-EC-0037
Date Received:	April 27, 2016
Project:	Georgia Triennial Review Standards Approval
Applicant:	USEPA

Dear Ms. Benante:

The U.S. Fish and Wildlife Service (Service) has reviewed the U. S. Environmental Protection Agency's (EPA) letter requesting consultation dated April 21, 2016, for the approval of revisions to the State of Georgia's water quality standards (WQS). Per their letter and associated Biological Evaluation (BE), the EPA requested concurrence on their determinations that specific revisions may affect, but are not likely to adversely affect any federally listed species. In a phone call between the Service and EPA on May 25th, 2016, the EPA also requested concurrence on their determinations that specific revisions would have no effect on federally listed species. This letter is submitted in accordance with section 7 of the Endangered Species Act of 1973, as amended (ESA) (87 Stat. 884; 16 U.S.C. 1531 *et seq.*).

PROPOSED WQS REVISIONS

In the BE, the EPA determined that three proposed WQS revisions would have no effect on listed species. These revisions include the removal of a footnote indicating that a portion of the Chattahoochee River is exempt from meeting WQS when flow falls below 750 cubic feet per second, a clarification of the definition for total lake loading of phosphorus, and the removal of a variance for a toxicity standard on Cabin Creek. The EPA also determined that a site-specific copper criterion in Buffalo Creek may affect, but is not likely to adversely affect the threatened finelined pocketbook mussel (*Lampsilis altilis*), the threatened northern long-eared bat (*Myotis septentrionalis*), the endangered gray bat (*Myotis grisescens*), and the endangered Indiana bat (*Myotis sodalis*).

Removal of streamflow footnote for the Chattahoochee River

Currently, a footnote in Georgia's Rule 391-3-6-.03(14) allows for WQS to be voided when flow in the Chattahoochee River between Peachtree Creek and Cedar Creek falls below 750 cubic feet per second. The proposed removal of the footnote will require that WQS for this section of the Chattahoochee River be met at all times, regardless of flow, which in turn should be more protective of ecological resources. Additionally, no listed species are believed to occur within this segment of the Chattahoochee River. The Service concurs with EPA's determination that the removal of the streamflow footnote in the Chattahoochee River will have no effect on federally listed species.

Clarification of the definition for total lake loading of phosphorus

A proposed revision in Rule 391-3-6-.03(17) clarifies that total lake loading of phosphorus for lakes with phosphorus standards is to be quantified as total phosphorus. As this revision is a simple clarification and does not institute new phosphorus loading standards, the Service concurs with EPA's determination that the clarification of total lake loading of phosphorus will have no effect on federally listed species.

Removal of a variance to the toxicity standard on Cabin Creek

A proposed revision in Rule 391-3-6-.06(4) removes a variance that granted an exception for whole effluent toxicity criteria for discharges from the Springs Industries Griffin Finishing Plant to Cabin Creek in Spalding County. The aforementioned facility closed in 2009; therefore the WQS exception is no longer needed. This segment of Cabin Creek will be subject to all applicable criteria. The Service concurs with EPA's determination that the removal of a variance to the toxicity standard on Cabin Creek will have no effect on federally listed species.

Adoption of a site-specific copper criterion for Buffalo Creek

A proposed revision in Rule 391-3-6-.03(5) establishes a site specific copper criterion for Buffalo Creek in Carroll County, Georgia. Currently, Buffalo Creek is subject to a copper criterion that is determined by a water hardness-based equation, where the allowable copper concentration correlates positively to measured hardness. The proposed copper criterion is based on the use of the Biotic Ligand Model (BLM) which incorporates additional water quality parameters into the determination of an allowable copper concentration. The use of the BLM to determine copper water quality criteria is fully described in an EPA document entitled "Aquatic Life Ambient Freshwater Quality Criteria- Copper, February 2007 Revision" (EPA-822-R-07-001). The Georgia Environmental Protection Division (EPD) determined, through a water sampling study in Buffalo Creek, that dissolved organic carbon (DOC) and pH accounted for much of the variability in the BLM output. In order to simplify the model for use by EPD, all other water quality parameters were set constant at worst-case values from the sampling study (worst-case being defined as the parameter values leading to the greatest copper bioavailability) and an equation was developed. EPD can now use measured DOC and pH values from Buffalo Creek in the equation to determine a specific copper criterion after each sampling event. Use of this modified BLM equation is expected to lead to a higher copper criterion than that determined by the previous hardness-based method. Development of the modified BLM model is detailed in a report prepared by Resolve Environmental Engineering, Inc. entitled "Biotic Ligand Model Report for Site-Specific Copper Water Quality Standard, Buffalo Creek, Carroll County, Georgia" dated February 2015.

Gray bat, Indiana bat, and northern long-eared bat

The gray bat, Indiana bat, and northern long-eared bat may occur in the vicinity of Buffalo Creek, though their specific use of the area is unknown. While the proposed copper criterion may allow copper concentrations in Buffalo Creek to increase above the current criterion under certain conditions, it is not anticipated that such an increase will impact the bat species. Copper is not expected to bioaccumulate in emergent aquatic insects that the bats may prey upon; therefore in the event that bats do forage above Buffalo Creek, their dietary dose of copper is not expected to be problematic. Additionally, the range of expected copper criterion values under the proposed BLM-based framework is several orders of magnitude below the National Primary Drinking Water Regulations (NPDWR) copper standard of 1.3 milligrams per liter. While the NPDWR copper standard is based on human health considerations, the mammalian-based data used to derive the standard should also be applicable to bats. Based on the information above, the Service concurs with EPA's determination that the proposed site specific copper criterion for Buffalo Creek may affect, but is not likely to adversely affect the gray bat, Indiana bat, and northern long-eared bat.

Finelined pocketbook

The finelined pocketbook is known to occur in the Tallapoosa River which is hydrologically connected to Buffalo Creek through the Little Tallapoosa River. The confluence of the Little Tallapoosa River and the Tallapoosa River is located a considerable distance from the confluence of Buffalo Creek and the Little Tallapoosa River (>30 miles when a straight line is drawn, not accounting for actual river miles due to the meander of the Little Tallapoosa River); therefore any water quality changes in Buffalo Creek would be expected to have minimal, if not negligible, influence on the Tallapoosa River. Additionally, there are no proposed changes to the current copper criteria in the Little Tallapoosa River, as it will still be subject to the current hardness-based copper criterion. Based on the distant location of finelined pocketbook occurrences and the negligible impact that Buffalo Creek water quality is expected to have on finelined pocketbook habitat in the Tallapoosa River, the Service concurs with the EPA's determination that the adoption of a site-specific copper criterion in Buffalo Creek may affect, but is not likely to adversely affect the finelined pocketbook.

This letter fulfills the requirements of section 7 of the ESA and further action is not required. If modifications are made to the Project, if additional information involving potential effects to listed species becomes available, or if a new species is listed, reinitiation of consultation may be necessary.

Thank you for your cooperation in the effort to protect fish and wildlife resources. If you have any questions regarding this project, please contact Anthony Sowers at 912-832-8739 extension 3.

Sincerely yours,

Strant Colwell

Strant T. Colwell
Coastal Georgia Supervisor

cc: electronic only
EPA, Atlanta, Georgia (Jason Poe, Cecelia Harper)
Service, Athens, Georgia (Robin Goodloe)
Service, Townsend, Georgia (Anthony Sowers)

DATA-QUALITY OBJECTIVES AND DATA QUALITY ASSESSMENT: APPLICATION OF THE BIOTIC LIGAND MODEL TO GENERATE WATER QUALITY CRITERIA FOR FOUR METALS IN SURFACE WATERS OF THE PAJARITO PLATEAU NEW MEXICO

Prepared for:
Los Alamos National Security

April 27, 2018

Prepared by: Windward environmental LLC

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Acronyms

%HA	percent humic acid
ACR	acute-to-chronic ratio
AOC	area of concern
AU	assessment unit
AWQC	ambient water quality criteria
BDL	below detection limit
BLM	biotic ligand model
DOC	dissolved organic carbon
DL	detection limit
DQA	data quality assessment
DQO	data quality objective
E	ephemeral
EIM	Environmental Information Management
EF	exceedance factor
EPA	US Environmental Protection Agency
ESA	Endangered Species Act
FAV	final acute value
FMB	fixed monitoring benchmark
gw	grams wet weight
I	intermittent
IP	individual permit
IWQC	instantaneous water quality criteria
LANL	Los Alamos National Laboratory
MLR	multiple linear regression
MTAL	maximum target action level
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
NMFS	National Marine Fisheries

NPDES	National Pollutant Discharge Elimination System
NTU	nephelometric turbidity unit
NWQMC	National Water Quality Monitoring Council
P	perennial
QC	quality control
SEP	supplemental environmental project
SMWU	storm water management unit
SR	state route
SSWQC	site-specific water quality criteria
SWQB	Surface Water Quality Bureau (of NMED)
TAL	target action level
TOC	total organic carbon
TU	toxic unit
USDA	US Department of Agriculture
USGS	US Geological Survey
WER	water effect ratio
Windward	Windward Environmental LLC
WM	snowmelt
WP	Persistent water
WQBEL	water quality-based effluent limit
WQS	water quality standard
WS	surface water
WT	storm water
WWTF	wastewater treatment plant

1 Introduction

The purpose of this document is to use the data quality objective (DQO) and data quality assessment (DQA) process to define an appropriate water quality dataset and then use it, in conjunction with the biotic ligand model (BLM), to generate preliminary ambient water quality criteria (AWQC) for aluminum, copper, lead, and zinc applicable to surface waters of the Pajarito Plateau in the vicinity of the Los Alamos National Laboratory (LANL). The BLM-based AWQC will be compared with current state of New Mexico AWQC for these four metals; the current New Mexico AWQC are based on hardness.

The BLM mechanistically accounts for the effects of multiple water chemistry variables on the bioavailability and toxicity of metals. This method is widely recognized nationally and internationally as the most scientifically advanced means of generating bioavailability-based AWQC. Typical BLMs employ measurements of up to 10 water quality variables, as described in Section 2. All BLMs characterize metal speciation and have the capacity to estimate metal toxicity to certain organisms, but only certain BLMs have been adapted to generate AWQC according to US Environmental Protection Agency (EPA) guidelines(EPA 1985), or other relevant international guidance. When in accordance with EPA guidelines, the AWQC generated by the BLM are regarded as instantaneous water quality criteria (IWQC), much like AWQC that are based on measurements of hardness at the time of sampling (i.e., state and EPA hardness-based AWQC).

EPA released nationally recommended AWQC for copper based on the BLM in 2007, after its initial draft in 2003 (EPA 2007, 2003a, b). In 2017, EPA considered a BLM for aluminum in its draft AWQC for that metal (EPA 2017). The state of New Mexico, like many other states, permits the use of the BLM as an option for generating SSWQC for copper, per EPA's 2007 copper AWQC (EPA 2007). However, SSWQC in general are subject to EPA review and approval until AWQC such as BLM-based copper criteria are adopted on a statewide basis; this recently occurred in the states of Idaho and Oregon (IDAPA 58.01.02, and OAR 340-041-8033 in (ODEQ 2016b, a) as a result of EPA Region 10 mandates related to Endangered Species Act (ESA) consultations on state WQS.

Ideally, the use of EPA's nationally recommended AWQC such as the 2007 BLM-based copper AWQC, would not lead to the need for SSWQC development for a particular location. In other words, EPA 2007 BLM-based copper AWQC should in one sense be as readily applicable as IWQC as are hardness-based copper AWQC stemming from EPA 1996 nationally recommended AWQC.

Key Definitions

- AWQC –ambient water quality criteria are state regulations or national policy documents and statements that define Section 304(a) criteria intended to broadly protect designated or beneficial uses regulated under the Clean Water Act; these regulations are applicable to wide geographic areas. AWQC are expressed as either fixed values or equations (models). The latter depend on one or more ambient water quality variables (e.g., hardness [metals], pH, or temperature [ammonia]) or more complex models such as multiple linear regression (MLR) models and the BLM.
- IWQC – Instantaneous water quality criteria are based on the application of AWQC to a particular set of values of dependent variables measured, calculated, or estimated for a particular set of conditions for a certain time at a location of interest. IWQC, by definition, will be time variable where dependent water quality parameters vary over time. Section 305(b) water quality assessments typically compare observed pollutant concentrations to concurrent IWQC.
- SSWQC – Site-specific water quality criteria (SSWQC) are AWQC that have been adjusted to local water quality conditions, typically to account for different bioavailability between the site of interest and laboratory toxicity testing waters used by EPA to generate nationally recommended AWQC. Typical SSWQC approaches include, but are not limited to, the water effect ratio (WER), recalculation, and resident species procedures (EPA 1994). SSWQC are typically used in long-term projections to determine the need for and set water quality-based effluent limits (WQBELs) in National Pollutant Discharge Elimination System (NPDES) permits. SSWQC are subject to EPA review and approval after adoption by state authorities in state water quality standards (WQS).

The DQO process, as described in Section 3, will be used to develop performance and acceptance criteria and to define study objectives with regard to using water quality data that have already been collected by LANL. Consequently, the focus of the DQO process will be to define the appropriate use of the existing data for the purpose of generating BLM-based IWQC. As an objectives-oriented and planning approach, the DQO process will establish data sufficiency and data handling rules that will help identify and minimize decision errors associated with analysis/project outcomes.

Each step of the DQO process is described in Section 3; given that data have already been obtained, Step 7 will be replaced with a description of a DQA. The DQA process (described in detail in Section 4) will evaluate the appropriateness and completeness of the data obtained from prior monitoring efforts conducted by LANL for surface waters of the Pajarito Plateau in the vicinity of LANL.

The focus of this evaluation process will be to maximize the number of appropriately usable water chemistry datasets for discrete surface water stormflow or baseflow sampling events. To characterize metal (i.e., copper, lead, zinc, and aluminum) bioavailability and calculate IWQC (using each applicable approach), a sufficient suite of BLM chemistry inputs is needed for each discrete water sampling event. The DQA process will identify the number of discrete sampling events for which complete or sufficiently complete BLM chemistry inputs are available and usable.

Sufficiently complete BLM chemistry inputs are somewhat dependent upon the metal being considered: For all of the metals in this evaluation, pH and dissolved organic carbon (DOC) are necessary key BLM inputs. Other chemistry inputs, such as alkalinity and hardness cations (e.g., calcium and magnesium), are also important, but values for these parameters can be estimated if information for other parameters is available. For example, alkalinity can be estimated from pH and the ambient concentration of carbon dioxide in the atmosphere, and major ions can be estimated from hardness and known or assumed ion ratios (Windward 2017). In addition, EPA (2016) provides nationwide eco-regional estimates (10^{th} percentiles) of most BLM inputs and describes analyses that, based on correlations between BLM inputs and conductivity and stream order, can be used to estimate missing values for BLM inputs. Both approaches are similar in that missing BLM inputs can be estimated for a water body of interest if certain water quality data are available, while other parameters are estimable as indicated in EPA (2016).

In addition to identifying sufficiently complete datasets, the DQA process will identify data gaps and will describe the outcomes of analyses intended to support applicable data substitutions or estimates. Generally, if the dataset is rich enough, substitution or estimation of missing data can be supported by evaluating potential relationships among water chemistry variables (e.g., relationships between DOC and total organic carbon [TOC], or relationships between major ions and hardness or specific conductance). After completion of the DQA process, the goal will be to use the aggregated dataset to perform analyses that will address the objectives of this study.

The overall objective of this work is to evaluate the use of the BLM as a potential approach for developing SSWQC for copper, lead, zinc, and aluminum applicable to surface waters of the Pajarito Plateau in the vicinity of LANL. The State of NM has only adopted EPA 2007 copper AWQC as an SSWQC option in state water quality standards (20.6.4.10.D((4)(c) NMAC).

Prior to evaluating the applicability of the BLM, the availability of a sufficiently robust dataset of BLM inputs must be established. To aid evaluations, IWQC will be calculated using multiple approaches, including current New Mexico and EPA hardness-based AWQC, and BLM-based IWQC. For aluminum, an additional approach will be to calculate IWQC based on the current MLR approach proposed by EPA in its 2017 draft aluminum AWQC (EPA 2017). Each approach will be used in the context of AWQC, so that the intended level of protection is consistent with EPA guidelines for AWQC (EPA 1985).

Comparisons of IWQC and potential water quality assessment outcomes generated using each of the approaches will provide information regarding potential decision errors between the more accurate BLM-based approach and nationwide or statewide AWQC approaches. Additionally, this evaluation will consider resolving time-variable IWQCs to potential SSWQC using applicable approaches driven by the richness of the dataset. For example, use of fixed percentiles of the IWQC distribution or the fixed monitoring benchmark (FMB) approach may be applicable at specific locations or spatial aggregations of interest.

Specific objectives of this work include:

- Communication of the purpose and appropriate use of the BLM for generating IWQC and approaches for developing SSWQC based on the BLM
- Generation of hardness- and BLM-based IWQC for copper, lead, zinc, and aluminum, and MLR-based IWQC for aluminum based on available datasets at a wide array of sampling locations and events
- Evaluation of the different assessment outcomes for each metal by comparing observed dissolved metals concentrations with each of the IWQC outcomes for each sampling event
- Calculation of FMBs where sufficient data are available (concurrent IWQC and metals concentrations)
- Consideration of various spatial aggregations with regard to using locations individually or combining locations according to spatial features or assessment units (AUs) recognized by the Surface Water Quality Bureau (SWQB) of the New Mexico Environment Department (NMED).
- Recommendation of potential SSWQC approaches, limitations, and outcomes (e.g., FMB, MLR equation, or percentiles of IWQC)

2 Background

This section provides background information about the development and use of the BLM, the LANL area waters and State of NM Water Quality Standards.

2.1 BLM Background

The BLM is depicted schematically in Figure 2-1. The BLM is a tool that can mechanistically predict the bioavailability of a variety of metals under the wide range of water chemistry conditions that are observed in surface waters. The BLM is scientifically robust and defensible, user friendly, and freely available. BLMs have been developed for metals in both freshwater and saltwater environments. Windward

Environmental LLC (Windward) staff developed the BLM software that the EPA adopted as the basis of its 2007 nationally recommended freshwater AWQC for copper. The states of Oregon and Idaho have adopted the EPA 2007 copper AWQC statewide[1] and use the Windward BLM software. Other states have adopted the copper BLM on a more limited basis.

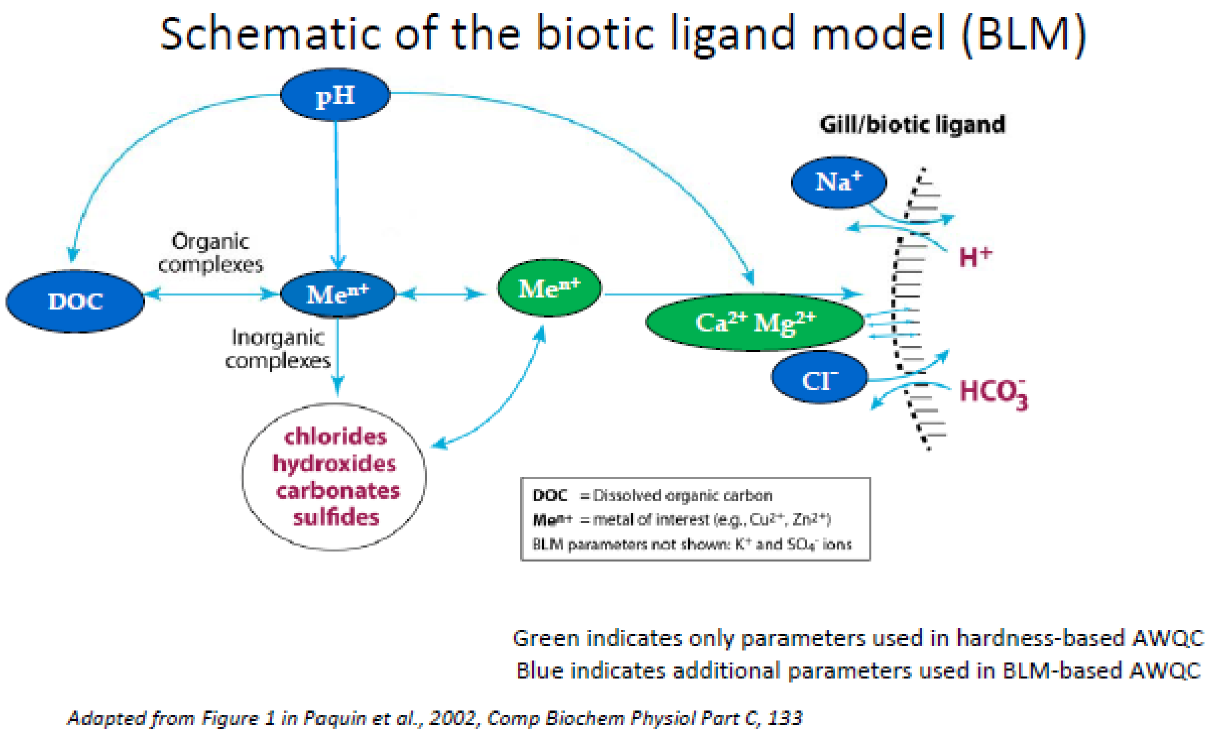

Figure 2-1.Schematic of the BLM

Several BLMs, including those for aluminum, lead, and zinc have been evaluated for potential use as water quality standards (e.g., Santore et al. 2018; DeForest et al. 2017; DeForest and Van Genderen 2012). In addition to generating AWQC consistent with EPA 1985 guidelines, the BLM software can also generate metal speciation data as well as predictions for a variety of toxicity endpoints for various organisms and metals.

The BLM executable program that drives the user-friendly Windows Interface version of the BLM software (available at: http://www.windwardenv.com/biotic-ligand-model/) can be used in batch mode (i.e., with a command prompt) to perform BLM calculations efficiently for large datasets. Coupled with a data analysis platform such

[1] Pursuant to ESA-related consultations on state WQS, EPA Region 10 required Oregon and Idaho to do away with hardness-based copper AWQC (EPA 1996 basis) and replace them, statewide, with EPA 2007 BLM-based AWQC for copper. As related to the 2012 National Marine Fisheries (NMFS) biological opinion (NMFS 2012), EPA did not approve the Oregon hardness-based copper AWQC (as well as other AWQC) in 2013 (EPA 2013). Similar ESA-related consultations in Idaho resulted in similar NMFS and EPA actions, leading to the 2015-2016 copper AWQC rulemaking and 2017 statewide adoption of copper BLM-based AWQC by Idaho.

as R (R Development Core Team 2010), the BLM executable provides a means to rapidly generate BLM outcomes (e.g., IWQC calculations, toxicity predictions for specific organisms/endpoints, or speciation calculations) for surface waters of interest. Such an approach, using the BLM in batch mode and R for analyses and graphics, was employed herein.

2.2 DESCRIPTION OF BLM INPUTS AND FUNCTIONS

Most metal BLMs, like the EPA 2007 copper BLM (EPA 2007), rely on 11 user inputs: pH, DOC, calcium, magnesium, sodium, potassium, sulfate, chloride, alkalinity, temperature, and percent humic acid (%HA). While %HA is an input parameter, measurements are not frequently available, so the BLM user's guide has recommended a default of 10% since EPA released the BLM-based copper AWQC in 2007 (HydroQual 2007; Windward 2015, 2017) Observed metals concentrations are not needed to generate BLM-based (or hardness-based) IWQC, because the IWQC depends only on the chemistry of the water of interest. Observed metals concentrations are needed for the purpose of generating toxic units[2] (TUs), which are the ratio of the observed metal concentration to the IWQC associated with a particular sample. The BLM user interface software generates TUs if user input is provided.

Observed metals concentrations are also needed to generate FMBs, which rely on distributions of observed metals and TUs. The FMB approach was first described in a 2008 report related to the approach's development and use in Colorado to address time-variable BLM-based IWQC (HydroQual 2008). EPA has been working on related FMB guidance (EPA 2012a), and more recent works further describe the FMB approach (Ryan et al. [in press]). The FMB approach is also mentioned as an implementation option in the Idaho and Oregon BLM-related copper AWQC documentation (McConaghie and Matzke 2016; IDEQ 2017).

Generally, measured concentrations in water samples that have been filtered through a 0.45-µm filter (i.e., operationally defined as dissolved concentrations) are used as BLM inputs. However, if it can be demonstrated that dissolved and total concentrations of BLM inputs are similar, then total (i.e., unfiltered) concentrations can be substituted if dissolved concentrations are not available for particular samples.

In addition to substitution approaches, it may be necessary to estimate concentrations for some BLM input parameters based on other measured parameters. However, this

[2] TUs are meant to describe the quotient of the measured metal concentration and the IWQC (e.g., [metal]/[IWQC]). This quantity can also be described as an exceedance factor (EF). Regardless of the term used to describe the quotient, it is intended to provide information about the relative magnitude of the measured metal concentration with respect to the IWQC. A value > 1 indicates that the metal concentration exceeds the IWQC magnitude, and a value < 1 indicates that the metal concentration is less than the IWQC magnitude. A TU > 1 does not by itself indicate a water quality standard violation, nor does it mean that toxicity has occurred or is likely to occur; the TU is intended as a frame of reference for initial decision making.

estimation approach is contingent upon a demonstration that such estimates are appropriate and defensible (e.g., calcium and magnesium may be estimated from hardness; DOC may be estimated from TOC; other cations or anions may be estimated from relationships with conductivity or specific conductance).

Another approach to substituting missing BLM inputs makes use of the ecoregion-specific "default" estimates proposed by EPA (2016). Such an approach is being used by the state of Oregon to generate "default" criteria for purposes of initial screening assessments (ODEQ 2016a, b; McConaghie and Matzke 2016), although based on state-specific datasets rather than the EPA 2016 values. In either case, this type of approach will only be considered during this evaluation if available data limitations are extensive. It is not anticipated that this type of approach will be necessary with the LANL dataset.

2.3 APPLICATION OF BLM-BASED AWQC

BLM-based AWQC are intended to be applied to ambient receiving waters subject to numeric criteria applicable to existing, designated, or attainable uses, such as those defined in 20.6.4.97 through 20.6.4.899 of the New Mexico Administrative Code (NMAC). While BLMs can be used to evaluate the potential toxicity of a particular discharge, BLM-based AWQC are not intended to be applied directly to discharges. The State of NM has only adopted EPA 2007 copper BLM-based AWQC as a SSWQC option in state water quality standards (20.6.4.10.D((4)(c) NMAC).

2.4 SURFACE WATERS OF THE PAJARITO PLATEAU IN THE LANL VICINITY

For the Pajarito Plateau waters in the vicinity of LANL, the NMED SWQB has assigned various AUs to particular groups of water bodies with designated aquatic life uses specified in 20.6.4.121, 126-128 NMAC. NMED's § 305(b) assessments have resulted in § 303(d) listings for a number of Pajarito Plateau AUs, especially those within or adjacent to LANL, determined to be impaired by metals such as aluminum, copper, and zinc (NMED 2012b, 2018).

The vast majority of water bodies in the LANL vicinity are classified as ephemeral or intermittent streams, which are designated for a limited aquatic life use (20.6.4.128 NMAC), so these water bodies are subject only to acute numeric criteria. Just a few water bodies in the area are classified as perennial waters with higher-level designated aquatic life uses that apply both acute and chronic criteria (e.g., Upper Sandia Canyon, and isolated segments of Canon de Valle and Pajarito canyons linked with springs; and Rio Frijoles in Bandelier National Monument [20.6.4.126 and 20.6.4.121 NMAC, respectively]).

A number of other water bodies outside of LANL but within greater Los Alamos County are not specifically classified in state standards, but are protected as default intermittent waters under 20.6.4.98 NMAC. These waters are designated with a marginal warm water aquatic life use, which in turn also applies both acute and chronic criteria. These waters are largely found in Pueblo, Bayo and Guaje Canyons and associated tributaries, as well as segments of Canon de Valle, Pajarito and Water canyons upstream of the LANL western boundary.

3 Data Quality Objectives

EPA's *Guidance on Systematic Planning Using the Data Quality Objectives Process* (EPA 2006) will be used to establish DQOs. Per EPA, "The DQO Process is used to develop performance and acceptance criteria (or data quality objectives) that clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions." Through DQO planning team involvement, the DQO process will systematically evaluate the problem, goals, and approach, as well as the intended use of the environmental data collected. EPA indicates that there are two primary types of intended use: decision making and estimation. The DQO process will identify the intended use and performance or acceptance criteria for the existing datasets provided by LANL necessary to meet the intended use.

The EPA DQO process is divided into the seven steps listed below:

1) State the problem.
2) Define study objectives.
3) Identify information inputs.
4) Define study boundaries.
5) Develop an analytical approach.
6) Specify performance and acceptance criteria.
7) Develop plan for obtaining data.

3.1 DQO Step 1: State the Problem

Current federal and certain state WQS lag behind scientific advances in understanding metal bioavailability. Therefore, decision making using existing WQS may lead to significant errors that either under- or over-protect aquatic environments.

Examples of scientific advancements that have yet to be implemented as regulatory policy include development of BLMs for several metals in addition to copper; EPA does not yet recommend these BLMs for use as AWQC. Mature BLMs that have been evaluated for potential use as AWQC, using guidelines for the derivation of AWQC (EPA 1985), include lead (DeForest et al. 2017) and zinc (DeForest and Van Genderen 2012). The aluminum BLM (Santore et al. 2018) and a MLR for aluminum (DeForest et al. 2018) have both been evaluated by EPA (2017) as potential tools to use for the derivation of aluminum AWQC.

These approaches characterize the influence of water chemistry on metal bioavailability, through either mechanistic (i.e., understanding chemical speciation and accounting for the effect of bioavailable species) or empirical (i.e., utilizing the direct relationships between water chemistry and observed effects) means, to predict the potential for adverse effects under various water chemistry conditions. Many current AWQC for metals consider water hardness as the only toxicity-modifying factor in surface waters; the failure to account for the effects of other toxicity-modifying factors (e.g., pH, DOC, alkalinity, etc.) may lead to AWQC that are not appropriately protective in the waters to which they are applied. In other words, outdated approaches could lead to false negative and false positive compliance decision-making errors, which might otherwise be alleviated or minimized by using the most current science: the BLM.

3.2 DQO Step 2: Identify Study Goals

3.2.1 Primary study goals

The study goals are:

- Identify and use appropriate data to generate BLM-based IWQC for locations on or around the Pajarito Plateau in the vicinity of LANL.
- Characterize the potential decision-making errors in using current state or EPA AWQC that might be eliminated or minimized by using BLM-based AWQC.
- Provide recommendations regarding potential use of the BLM for the derivation of SSWQC outcomes.

In addition to BLM-based AWQC, other approaches—such as the MLR for aluminum described by DeForest et al. (2018) for characterizing the effects of toxicity-modifying factors (other than hardness)—will be considered.

3.2.2 Possible outcomes from the study

If application of the BLM to waters of the state on the Pajarito Plateau in the vicinity of LANL indicates that current AWQC are under- or over-conservative, then stakeholders could consider the following:

1) Alternative 305(b) assessments using the BLM, which could lead to an alternative determination, wherein the BLM shows that application of NMAC AWQC leads to false positives, or conversely, supporting a 303(d) Category 5 listing wherein the BLM shows that application of NMAC AWQC leads to false negatives
2) Implementing BLM-based AWQC, such as via SSWQC for the Pajarito Plateau waters appropriately characterized

3) More broadly adopting BLM-based AWQC as statewide options subject to the "performance-based" approach recommended by EPA (Wilcut and Beaman 2015).

If BLM-based SSWQC are demonstrated to be feasible for surface waters on the Pajarito Plateau in the vicinity of LANL, communication regarding the appropriate use of the BLM and/or other bioavailability-based WQC approaches should be provided as next steps.

3.3 DQO Step 3: Identify Information Inputs

3.3.1 Types of information needed

The following types of data and information are needed:

- Sufficiently complete sets of BLM input parameters for discrete water sampling events for surface waters in the LANL vicinity. Table 3-1 provides information regarding the importance and use of each BLM input parameter.
- Data for related parameters such as TOC, hardness, conductivity, and specific conductance should also be compiled for the purpose of evaluating potential strategies for filling data gaps for BLM inputs.
- Water chemistry data used for BLM calculations should have an appropriate "pedigree:" a defined sampling plan, sampling and analytical methods, sample handling, and quality control (QC) review.
- Generally, BLM inputs refer to dissolved concentrations (i.e., in sample filtered through a 0.45-µm filter prior to analysis), because the chemical interactions characterized by the BLM do not consider solubility or the presence of solid phases (with the exception of amorphous aluminum hydroxide(s) when predicting effect concentrations for aluminum). However, total (i.e., unfiltered) concentrations for BLM inputs will be considered as substitutions for dissolved concentrations if these types of substitutions are supported by the data.
- Measured dissolved metals concentrations are necessary for copper, lead, and zinc so that TUs can be computed (a TU being the ratio of an observed dissolved metal concentration to IWQC generated for the water chemistry in that same sample).
- For aluminum, unfiltered ("UF," i.e., total) and filtered concentrations (using filter pore sizes of 10-, 1-, and 0.45-µm; denoted as F10, F1, and F or F0.45, respectively) will be used for comparisons with IWQC and for calculation of TU values corresponding to each sample preparation type. Preparing computations based on all four bases for aluminum (UF, F0.45, F1 and F10) will help illustrate the potential differences in outcomes for the various sample preparations currently under consideration (UF by EPA 2017, F10 by NMED, F1 by LANL as a potential improvement over F10, and F0.45 status quo "dissolved").

The data and information inputs described above will determine the number of BLM-based IWQC that can be generated for the particular waters that have sufficient data. The EPA's recommended default estimated BLM input values for local ecoregions will not be employed, but they may be used for relativistic comparisons that might be instructive when considering further extrapolation. Aggregation of the BLM input data will identify where data gaps exist. Simultaneous aggregation of data for other water chemistry characteristics (e.g., TOC, hardness, specific conductance, etc.) will allow for evaluation of potential strategies to fill data gaps while systematically documenting which events are affected by data substitutions. Documenting substitutions will facilitate the identification of uncertainties associated with BLM-based IWQC calculations.

Table 3-1. BLM input parameters

Parameter	Comments
Metal of interest (e.g., aluminum, copper, lead, zinc)	not necessary for calculation of IWQC, but necessary to calculate TUs (or exceedance factors)
Temperature	required for all BLMs
pH	necessary for speciation and competing ion; required for all BLMs
DOC	necessary for speciation; required for all BLMs[a]
%HA	typically assumed to be 10% per BLM User Guides (i.e., 10% of organic matter assumed to be humic acid); required for all BLMs
Calcium (Ca)	necessary as a competing ion; required for all BLMs[b]
Magnesium (Mg)	necessary as a competing ion; required for all BLMs[b]
Sodium (Na)	necessary as a competing ion; required for all BLMs[b]
Potassium (K)	necessary for charge balance; required for all BLMs[b]
Sulfate (SO_4)	necessary for charge balance; required for all BLMs[b]
Chloride (Cl)	necessary for charge balance; required for all BLMs[b]
Alkalinity	necessary for inorganic speciation calculations; required for all BLMs[c]

[a] Input for DOC is needed; if missing, fraction of TOC could be substituted, if relationship is demonstrated.

[b] Input for major ions is needed; if missing, could be estimated from hardness, conductivity, specific conductance, or location average, if relationships are identified or if substitution is deemed defensible (HydroQual 2007; EPA 2016).

[c] If missing, alkalinity can be estimated using pH and atmospheric carbon dioxide (HydroQual 2007).

%HA – percent humic acid
BLM – biotic ligand model
DOC – dissolved organic carbon
IWQC – instantaneous water quality criteria
TOC – total organic carbon
TU – toxic unit

3.3.2 Sources of information needed

The primary source of information for this evaluation will be surface water monitoring data collected by LANL. The data will be queried and extracted from LANL's Environmental Information Management (EIM) database. Data collected by NMED will not be used because they lack measured DOC data. In addition to data from

LANL, surface water data from the National Water Quality Monitoring Council (NWQMC) will be used to identify other relevant data for surface waters in the LANL vicinity and greater New Mexico area (e.g., the Rio Grande at Otowi Bridge, Rio Grande below Cochiti Dam, and Rio Grande at San Felipe). The NWQMC's data portal consolidates water quality data from EPA's STORET database, the US Geological Survey's (USGS's) National Water Information System database, and the US Department of Agriculture's (USDA's) STEWARDS database (https://www.waterqualitydata.us/wqp_description/).

3.4 DQO Step 4: Define Study Boundaries

3.4.1 Temporal boundaries

The temporal boundaries associated with this effort will be determined by the time periods over which sufficiently complete BLM input data exist for surface waters in the LANL vicinity. If supplemental data are obtained for additional waters within the LANL vicinity (e.g., the Rio Grande), the temporal boundaries associated with those data will be dictated by national water monitoring programs at various historical and current monitoring locations. Surface water sampling events can be either some form of dry weather baseflow (springs, snowmelt) or wet weather stormflow generated by rainfall; both baseflow and stormflow can be sampled by one or more of LANL's storm water monitoring programs.

Regarding appropriate application of IWQC calculations for AWQC durations, the temporal nature of the receiving water will be considered. Acute IWQC will be relevant for all locations that are considered ephemeral, intermittent, or perennial waters. Chronic IWQC will be relevant only for defined perennial waters in the area: Frijoles in Bandelier [20.6.4.121 NMAC] and perennial waters within LANL [20.6.4.126 NMAC]. If usable data are available, chronic IWQC may also be evaluated for the effluent-dependent waters in upper Sandia Canyon and lower Pueblo Canyon as they relate to the discharges from the LANL wastewater outfall 001, and Los Alamos County wastewater treatment plant, respectively.

3.4.2 Spatial boundaries

BLM-based IWQC will be generated for each of the surface water locations in the LANL vicinity that have usable datasets. These locations are generally similar to those identified in the 2017 sampling and monitoring supplemental environmental project (SEP) DQOs (LANL 2017a). The locations are expected to represent a broad array of surface waters that include the major and minor watersheds on the Pajarito Plateau in the LANL vicinity. LANL has already characterized the watersheds associated with many sampling locations as predominated by either developed or undeveloped characteristics. Sampling locations within some of the developed watersheds have been designated as "Site," because they are downstream from actual or potential storm water runoff from solid waste management units and areas of concern regulated under LANL's NPDES individual permit.[3]

Numerous locations within undeveloped watersheds have been sampled extensively as part of past efforts to characterize natural background concentrations of various constituents stemming from upstream locations, i.e., the LANL western boundary, and Northern Reference Watersheds(LANL 2014, 2013, 2012). In addition, more recent sampling programs were develop to characterize additional natural background reference locations further removed and upwind from LANL activity, i.e., the new SEP Reference Watershed monitoring commenced in 2017(LANL 2017a). Where usable data exist, BLM-based IWQC will be generated for nearby perennial waters where the USGS operates monitoring stations (e.g., Rio Grande River).

3.5 DQO Step 5: Develop Analytical Approach

The source dataset will be provided by LANL, based on a query of the LANL EIM database constructed to provide all available records for the following:

1) BLM analytes, starting with pH & DOC pairs
2) Secondary analytes that can aid in filling data gaps and further interpretation of the BLM dataset and outcomes
3) Water sample types including surface water (WS), snowmelt (WM), persistent flow (WP), and storm water (WT)
4) Sampling location names, aliases, and coordinates for known surface waters
5) QC and other information available from EIM

LANL staff will provide additional information about sample locations (e.g., developed/undeveloped landscape designations, major/minor watershed names). LANL staff will also identify data potentially affected by wild fires; fire-affected data will not be removed but will be plotted separately in various evaluations to help visualize potential anomalies.

The LANL dataset will be aggregated and evaluated to determine the extent to which BLM-based IWQC can be generated for each discrete event for the locations provided. Initial dataset aggregation will be intended to identify the number of complete BLM scenarios that can be considered, as well as the number of data gaps present. Subsequent to initial dataset aggregation, strategies to fill data gaps will be evaluated.

For the purpose of calculating BLM-based IWQC, a measurement of pH and organic carbon for each sampling event will be required (either measured DOC or an

[3] Collectively, LANL refers to storm water management units (SWMUs) and areas of concern (AOCs) as "Sites" (with a capital "S").

appropriate estimate of DOC calculated from measured TOC). Steps for establishing BLM inputs for any sampling event include:

1) With the exception of alkalinity, DOC, and pH, determine measured concentrations of each input from filtered samples for each event.
2) If measured concentrations are not available from filtered samples, determine if measured concentrations are available from an unfiltered sample from the same event, and evaluate if those data can be used to determine estimates.
3) If measured concentrations are not available from filtered or unfiltered samples, determine if BLM input can be estimated from another water chemistry characteristic (e.g., hardness or specific conductance).
4) If measured concentrations are not available from filtered or unfiltered samples, determine if a location-specific estimate (e.g., location average) can be used as an estimate.
5) If no data are available for a BLM input, determine if regional information can be used.
6) If no data are available for a BLM input, and regional information are not available or suitable, perform a sensitivity analyses to identify an appropriately conservative input value (this may be most appropriate for temperature).

During data aggregation and summary, supporting information will be provided to demonstrate the adequacy and defensibility of strategies used to fill data gaps. It is known that temperature data are missing for the entire dataset, so a uniform temperature will need to be assumed, and a sensitivity analysis will need to be performed across the range of BLM calibration temperatures, e.g., 10 to 25 °C specified in the BLM user's guides (HydroQual 2007; Windward 2015).

Detection statuses of analyte concentrations will be considered during data aggregation, and BLM inputs will be treated differently than the metals of interest (i.e., aluminum, copper, lead, and zinc). For BLM input parameters, concentrations that are flagged as below detection limit (BDL) or not detected will be replaced by ½ of the reported detection limit (DL). Because a zero concentration is not allowed as an input to the BLM, a substitution approach using ½ of the reported DL is reasonable, as other approaches (e.g., maximum likelihood estimation and regression on order statistics) are not appropriate for discrete samples. When the concentration of a metal of interest is reported as BDL, the DL will be used and the sample will be flagged as BDL. This convention is used so that comparisons between metal concentrations and associated IWQCs will be conservative. Generally, concentrations of BLM inputs are not often affected by detection limits, whereas metals concentrations are affected more frequently.

Using the aggregated data, IWQC will be generated for each metal considered using the approaches described in Table 3-2, summarized as follows:

- Aluminum:
  - BLM-based chronic (and potentially acute) WQC using Santore et al. (2018)
  - MLR-based acute AWQC using EPA (2017) [4]
  - Hardness-based acute WQC using NMAC.20.6.4.900(I)
- Copper:
  - BLM-based acute AWQC using (EPA 2007)
  - Hardness-based acute WQC using NMAC. 20.6.4.900(I)
- Lead:
  - BLM-based acute AWQC using DeForest et al. 2017
  - Hardness-based acute WQC using NMAC. 20.6.4.900(I)
- Zinc
  - BLM-based acute AWQC using DeForest and Van Genderen (2012)
  - Hardness-based acute WQC using NMAC.20.6.4.900(I)

The relevant BLMs will be applied to the aggregated BLM input dataset using the BLM binding constants provided in Table 3-3, which represent the strength of binding of bioavailable metal species and competing cations to the biotic ligand. Reactions at the biotic ligand are characterized as equilibrium complexation reactions at a toxicologically relevant surface (e.g., gill surface), facilitating the competitive interactions among metal species and competing cations. The BLM parameter descriptions for copper, lead, and zinc are taken directly from EPA (2007), DeForest et al. (2017), and DeForest and Van Genderen (2012), respectively. For aluminum, the BLM description in Table 3-3 represents calibration to chronic toxicity data and is taken directly from Santore et al. (2018). A conservative translation of chronic aluminum IWQC to acute aluminum IWQC will be performed using an acute-to-chronic ratio (ACR) derived from EPA (2017). If resources are sufficient to apply the chronic aluminum BLM to the acute AWQC dataset described by EPA (2017), a direct calculation of acute aluminum IWQC may be performed using the aluminum BLM described by Santore et al. (2018).

[4] The EPA (2017) MLR approach uses the following equations from DeForest et al. (2018) to normalize the acute and chronic species sensitivity distributions for aluminum to facilitate calculation of WQC:

Normalized Invertebrate ECX =

$$exp^{(\ln(ECX_{meas})-0.525*(\ln(DOC_{meas})-\ln(DOC_{site}))-11.282*(pH_{meas}-pH_{site})-2.201*(\ln(hardness_{meas})-\ln(hardness_{site}))+0.663*(pH^2_{meas}-pH^2_{site})+0.264*(pH_{meas}*\ln(hardness_{meas})-pH_{site}*\ln(hardness_{site})))}$$

Normalized Vertebrate ECX =

$$exp^{(\ln(ECX_{meas})-0.503*(\ln(DOC_{meas})-\ln(DOC_{site}))-3.131*(pH_{meas}-pH_{site})-3.443*(\ln(hardness_{meas})-\ln(hardness_{site}))+0.494*(pH_{meas}*\ln(hardness_{meas})-pH_{site}*\ln(hardness_{site})))}$$

Table 3-2. AWQC calculation approaches

Metal	Approach	Description	Reference
Aluminum	aluminum BLM	mechanistic characterization of dissolved and precipitated aluminum bioavailability	Santore et al. (2018)
	New Mexico WQC	hardness equation	NMAC.20.6.4.900(I)
	draft EPA WQC	MLR with pH, DOC, hardness	EPA (2017)
Copper	BLM	EPA-recommended WQC	EPA (2007)
	New Mexico WQC (= EPA 1996 WQC)	hardness equation	NMAC.20.6.4.900(I)
Lead	BLM	mechanistic characterization of dissolved lead bioavailability	DeForest et al. (2017)
	New Mexico WQC (= EPA 1996 WQC)	hardness equation	NMAC.20.6.4.900(I)
Zinc	BLM	mechanistic characterization of dissolved zinc bioavailability	DeForest and Van Genderen (2012)
	New Mexico WQC	hardness equation	NMAC.20.6.4.900(I)

BLM – biotic ligand model
DOC – dissolved organic carbon
EPA – US Environmental Protection Agency
MLR – multiple linear regression
NMAC – New Mexico Administrative Code
WQC – water quality criteria

The hardness- and MLR-based equations for aluminum AWQC described above, will also be applied to the BLM input dataset. For all approaches utilizing hardness to generate IWQC, hardness will be either the value reported for filtered samples, or the value calculated based on calcium and magnesium concentrations reported for filtered samples.

Where suitable observed metal concentrations are available (i.e., dissolved concentrations for copper, lead, and zinc; total and dissolved concentrations for aluminum), they will be compared to calculated IWQC. These comparisons will be made by calculating a TU (or quotient of the reported metal concentration and the IWQC) for each approach that is used to calculate IWQC (e.g., hardness-, MLR-, or BLM-based). When a metal concentration is flagged as BDL and is then compared to a calculated IWQC by determination, the TU will be described as less than the calculated value.

Table 3-3. BLM-binding constants for copper, lead, zinc, and aluminum

Biotic Ligand Model Parameter	Copper (EPA 2007)	Lead (DeForest et al. 2017)	Zinc (DeForest and Van Genderen 2012)	Aluminum (Santore et al. 2018)
Biotic ligand (BL) reactions with specified chemical constituent; logarithm of equilibrium constant is shown (i.e., Log K)[a]				
BL-H	5.4	4	6.39	5.4
BL-Ca	3.6	5.1	3.82	4.8
BL-Mg	3.6	4	3.31	
BL-Na	3	4.2	2.59	3.3
BL-Cu	7.4	X	X	X
BL-CuOH	-1.3	X	X	X
BL-Pb	X	6.65	X	X
BL-PbOH	X	-0.4	X	X
BL-Zn	X	X	5.41	X
BL-ZnOH	X	X	-2.4	X
BL-Al	X	X	X	4.4
BL-AlOH	X	X	X	-1.9
BL-$Al(OH)_2$	X	X	X	-7.75
BL-$Al(OH)_4$	X	X	X	-21
BL-AlF	X	X	X	8.5
Sensitivity parameters for calculating 5th percentiles of genus sensitivity distributions[b]				
Acute critical accumulation (nmol/gw)	0.03395	0.0628	5.388	na
Chronic critical accumulation (nmol/gw)	X	0.000341	0.345	na
ACR ratio (if used)	3.22	X	X	5

[a] Log K represents the overall formation of the biotic ligand (BL) complex indicated. For example: $BL^- + Cu^{2+} + OH^- = BL\text{-}CuOH$; Log K = -1.3.

[b] Acute and chronic critical accumulation values represent the amount of metal required at the biotic ligand to elicit an effect commensurate with the 5th percentile of the acute or chronic genus sensitivity distribution.

ACR – acute-to-chronic ratio na – not applicable gw – grams wet weight

The calculated TUs will be used as a basis for evaluating the frequency of decision errors that may be encountered when using a hardness-based IWQC approach vs. a BLM-based IWQC approach. To evaluate potential decision error frequencies among the various AWQC bases, a quadrant diagram will be used (Figure 3-1). Such diagrams provide a simple summary of the relative differences among potential outcomes, and the magnitude of those differences when using different approaches to generate IWQC.

- TUs plotted in the lower right quadrant indicate a "false positive" where TUs are > 1 based on hardness but < 1 based on the BLM[5].
- TUs plotted in the upper left quadrant indicate a "false negative" where TUs are < 1 based on hardness, but > 1 based on the BLM.
- TUs plotted in the upper right and lower left quadrants indicate equivocal results (exceedances and non-exceedances, respectively).
- Perfect agreement between the two outcomes would be indicated by data points falling on the 45 degree line intersecting the origin (where the TU axes cross at values of 1).
- Relative discord between outcomes increases logarithmically as data points fall further from the 45 degree line. In other words, besides decision errors, tendencies towards incipient errors can also be visualized rapidly using quadrant plots like Figure 3-1.

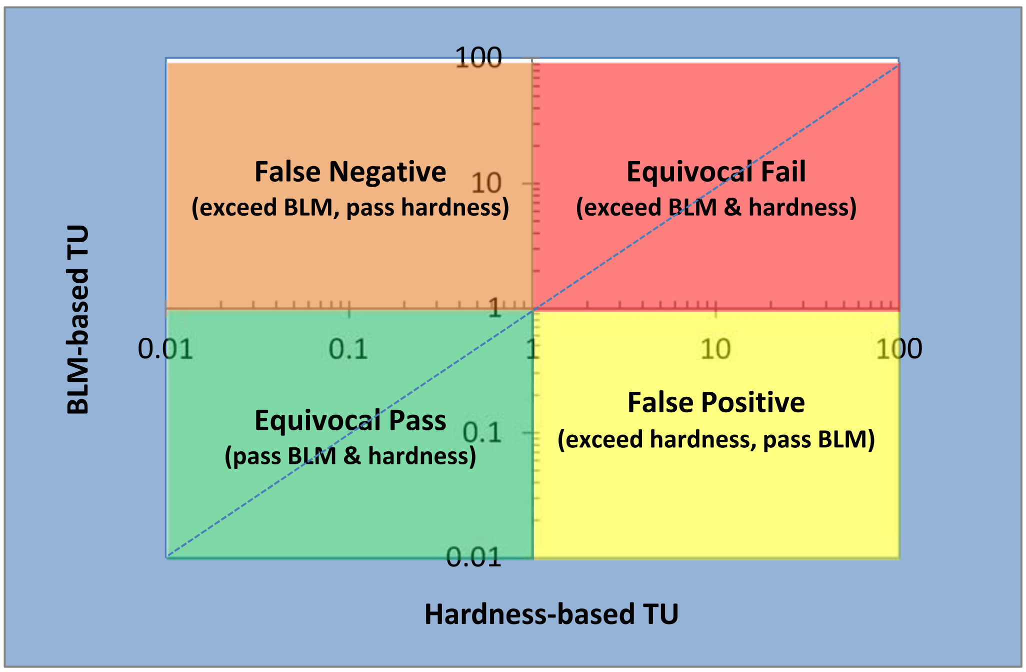

Figure 3-1. TU quadrant diagram for evaluating decision error frequency and magnitudes

In addition to the simple comparisons of various IWQC approaches, TUs can be used with reported concentrations and IWQCs to calculate FMBs for a given location (Ryan et al. [accepted]). An FMB for a given location is intended to provide a benchmark

[5] For aluminum, TU quadrant diagrams will also be used to compare the EPA 2017 MLR-based IWQC with hardness-based IWQC.

that, if not exceeded, is an indicator of WQC attainment. An FMB has potential utility as a SSWQC when IWQC time variability needs to be taken into account but is contingent upon the availability of a sufficient number of BLM datasets with BLM inputs and concurrent observed metals data.

With respect to the number of samples needed for calculation of FMBs, a definitive number of samples necessary is not known *a priori*. FMB calculations are affected by the variability of measured metal concentrations and calculated IWQCs, and their correlation. For the purpose of generating initial FMBs, calculations will only be performed when ten or more paired metal and IWQC observations are available for a particular location (or other relevant level of spatial scale). The FMB approach was originally developed for discrete locations (e.g. those downstream from a wastewater outfall), but aggregation of locations among AUs will be considered for this project, as well as potential larger spatial scales (watersheds) and different temporal scales (base flow vs. storm flow).

3.6 DQO Step 6: Specify Performance and Acceptance Criteria

The performance and acceptability of the BLM-based IWQC results will be primarily based on whether sufficient water chemistry data are available to generate BLM-based IWQC for the locations of interest. If data substitutions or estimates are necessary for the most important/sensitive BLM inputs (pH & DOC), the results of the BLM will be qualified as uncertain.

Performance criteria include:

- BLM- and other bioavailability-based WQC calculations should be performed only when pH and organic carbon (preferably DOC, but substitution based upon TOC may be appropriate) are measured for the same water sampling event.
- Substitution or estimation of other missing BLM input parameters should be supported by available data (e.g., relationship between dissolved and total concentration of input parameter).
- To evaluate potential decision errors based on various approaches for calculating WQC, measured metal concentrations must be available so that TUs can be calculated.
- To use the FMB approach to derive potential site-specific benchmarks, a sufficient number of TUs should be available (sufficient number depends on behavior of the data [i.e., distributions, correlations, variability]).

Acceptance criteria include:

- Sampling locations should be verified as surface waters (i.e., lying on NMED SWQB AUs) and not direct storm water discharges from developed areas.
- Data used for calculations should be validated.

- Models used for calculations should be applicable and defensible for the purpose of calculating WQC.
- Uncertainty should be characterized qualitatively and quantitatively (where possible) for decision making.

3.7 DQO Step 7: Develop Plan for Obtaining Data

Surface water data, including BLM inputs, have been collected by LANL at a variety of locations since 2005. Routine monitoring for BLM inputs appears to have begun in 2013 at many additional locations. To perform the analyses described above, water quality data associated with receiving water samples collected by LANL were requested in January 2018. Data were queried by LANL staff from LANL's EIM database and provided in Excel format. Supplemental water quality data for the Rio Grande and other locations of potential interest will be obtained from the water quality portal: https://www.waterqualitydata.us/wqp_description/

4 Data Quality Assessment

This section describes the results of the DQA for the BLM dataset provided by LANL. A dataset, consisting of 95,743 records for various analytes (including BLM inputs) from 66 different locations was provided by LANL. This dataset was generated by a number of LANL monitoring programs that are understood to have had specific sampling plans and data quality comparable to those evaluated in LANL's recent sampling and monitoring SEP DQO/DQA (LANL 2018a, 2017a).

The LANL BLM dataset comprised 48 locations[6], which were surface water sampling locations known or believed to represent many surface water AUs recognized by the NMED SWQB. LANL provided the list of sampling locations with additional information that was used for these determinations[7] (Table 4-1). The 48 surface water sampling locations in the LANL BLM dataset represent two distinct groups: 1) 12 surface waters with watersheds outside of, or upstream from the LANL facility and Los Alamos town site ("undeveloped" landscape type in Table 4-1), and 2) 36 surface waters within or downstream from the LANL facility and Los Alamos town site and other unincorporated areas of Los Alamos County ("Site" landscape type in Table 4-1).

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[6] Data provided by LANL for 18 locations were excluded from the BLM dataset because they represented storm water discharge locations deemed inappropriate for the application of AWQC, i.e., they are not sampling locations in surface water AUs

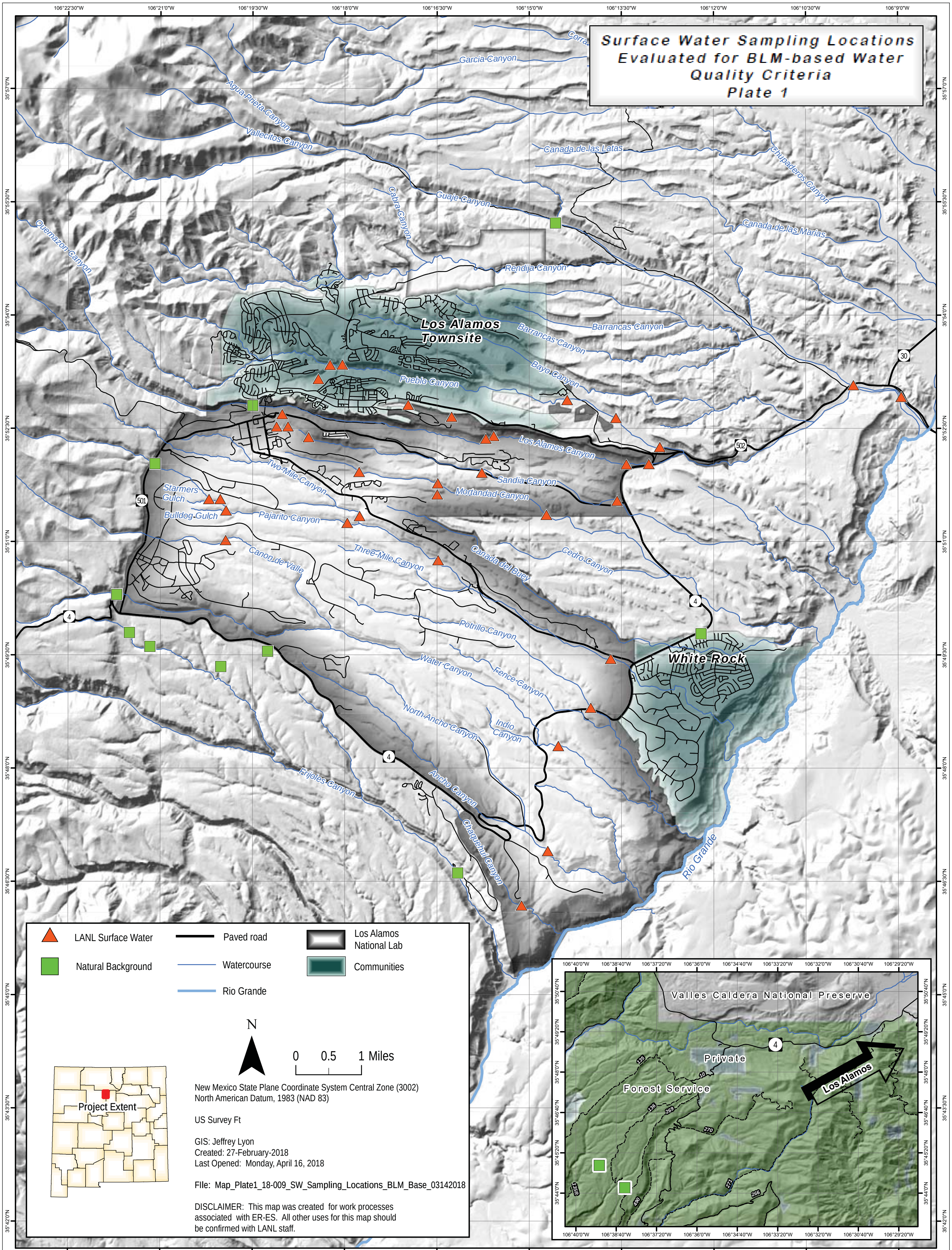
[7] Sample location names were simplified by Windward to aid evaluations and plotting (the more information-rich mnemonics were selected between choices of Location ID and Location Alias).Windward also used GIS tools to measure distances to the nearest AU (based on NMED shapefiles for AUs.) In many cases in Table 4-1, the distances are considerable because sampling locations on small tributaries are well-removed from the mapped AU main stems.

Of the 12 upstream/offsite locations, 7 locations have been characterized as "natural background" locations[8] in various LANL reports that have characterized background water quality conditions(LANL 2007, 2010b, 2013, 2014, 2015, 2017b, 2018a), four locations are being characterized as part of the SEP[9], and 1 location is in Bandelier National Monument (E350). The 36 downstream locations ("Site" landscape type in Table 4-1) are some of the numerous gaging stations operated by LANL with relatively long periods of water quality and discharge monitoring data. All surface water sampling locations with sufficient BLM datasets, as described below, are shown in Plate 1.

In addition to results for the LANL dataset, supplemental BLM datasets from the NWQMC database for locations in New Mexico were acquired and evaluated. This dataset included data for a total of 18 locations in New Mexico, but most locations, with the exception of those from the Rio Grande, contained ≤ 5 complete BLM sampling events. Thus, the BLM evaluations will focus on the five Rio Grande locations.

[8] E026, E240, E252, Guaje-REF-2, BAND-REF-3, BAND-REF-4, WR-REF-3

[9] The four SEP reference watershed locations are designated in Table 4-1 with location IDs beginning with "SEP".



Surface Water Sampling Locations Evaluated for BLM-based Water Quality Criteria
Plate 1
Garcia Canyon
Agua Prieta Canyon
Vallecitos Canyon
Canada de las Latas
Chupaderos Canyon
Cabra Canyon
Guaje Canyon
Canada de las Marias
Quemazon Canyon
Rendija Canyon
Los Alamos Townsite
Barrancas Canyon
Bayo Canyon
Pueblo Canyon
Los Alamos Canyon
Two Mile Canyon
Sandia Canyon
Mortandad Canyon
Starmers Gulch
Bulldog Gulch
Pajarito Canyon
Canon de Valle
Three Mile Canyon
Canada del Buey
Cedro Canyon
Potrillo Canyon
Water Canyon
Fence Canyon
White Rock
North Ancho Canyon
Indio Canyon
Frijoles Canyon
Ancho Canyon
Chaquehui Canyon
Rio Grande
30
502
501
4
LANL Surface Water
Natural Background
Paved road
Watercourse
Rio Grande
Los Alamos National Lab
Communities
N
0 0.5 1 Miles
Project Extent
New Mexico State Plane Coordinate System Central Zone (3002)
North American Datum, 1983 (NAD 83)
US Survey Ft
GIS: Jeffrey Lyon
Created: 27-February-2018
Last Opened: Monday, April 16, 2018
File: Map_Plate1_18-009_SW_Sampling_Locations_BLM_Base_03142018
DISCLAIMER: This map was created for work processes associated with ER-ES. All other uses for this map should be confirmed with LANL staff.
Valles Caldera National Preserve
Private
Forest Service
Los Alamos

Table 4-1. BLM evaluation locations

Location ID	Location ID Alias	Windward ID	Major Watershed	Minor Watershed	Landscape	Fire-affected Watershed	Y Axis	X Axis	Water Type	NMAC Class	Hydrology (E/I/P)	Nearest AU	Nearest AU Distance (ft)	Notes
Acid above Pueblo	E056	E056	Pueblo	Acid	site	no	1778790.921	1624431.601	surface water	98	intermittent	NM-97.A_002	54	
South Fork of Acid Canyon	E055.5	E055.5	Pueblo	Acid	site	no	1777746.088	1623467.575	surface water	98	intermittent	NM-97.A_029	11	
Ancho below SR-4	E275	E275	Ancho	Ancho	site	not determined	1739818.299	1641902.732	surface water	128	E/I	NM-9000.A_054	52	
La Delfe above Pajarito	E242.5	E242.5	Pajarito	Arroyo de la Delfe	site	yes	1767185.074	1616053.533	surface water	128	E/I	NM-128.A_16	17	
Canon de Valle below MDA P	E256 Canon de Valle below MDA P	E256	Water	Cañon de Valle	site	yes	1764811.076	1616017.769	surface water	126	perennial	NM-126.A_00	50	
Chaquehui at TA-33	E338	E338	Chaquehui	Chaquehui	site	not determined	1735450.235	1639792.836	surface water	128	E/I	NM-128.A_03	2.5	
DP above Los Alamos Canyon	E040	E040	Los Alamos	DP	site	yes	1773169.199	1637555.718	surface water	128	E/I	NM-128.A_10	32	
DP above TA-21	E038	E038	Los Alamos	DP	site	yes	1775660.775	1630683.66	surface water	128	E/I	NM-128.A_14	19	
DP below grade ctrl structure	E039.1	E039.1	Los Alamos	DP	site	yes	1774716.075	1634183.14	surface water	128	E/I	NM-128.A_10	9	
Guaje at SR-502	E099	E099	Los Alamos	Guaje	site	yes	1777248.77	1666451.92	surface water	98	intermittent			no AU in lower Guaje in Pueblo land
Los Alamos above DP Canyon	E030	E030	Los Alamos	Los Alamos	site	yes	1772912.232	1637449.1	surface water	128	E/I	NM-9000.A_063	41	
Los Alamos above low-head weir	E042.1	E042.1	Los Alamos	Los Alamos	site	yes	1770891.744	1648209.644	surface water	128	E/I	NM-9000.A_006	26	
Los Alamos above Rio Grande	E1099	E1099	Los Alamos	Los Alamos	site	yes	1776310.43	1670298.54	surface water	98	intermittent			no AU in lower Los Alamos Cyn in Pueblo land
Los Alamos below low-head weir	E050.1	E050.1	Los Alamos	Los Alamos	site	yes	1770920.631	1650021.007	surface water	128	E/I	NM-9000.A_006	17	
Mortandad above Ten site	E201	E201	Mortandad	Mortandad	site	no	1769370.925	1633074.678	surface water	128	E/I	NM-9000.A_042	38	
Mortandad at LANL Boundary	E204	E204	Mortandad	Mortandad	site	no	1766832.164	1641803.501	surface water	128	E/I	NM-9000.A_042	17	
Mortandad below Effluent Canon	E200	E200	Mortandad	Mortandad	site	no	1770288.738	1626750.385	surface water	128	E/I	NM-9000.A_042	44	
Pajarito above SR-4	E250	E250	Pajarito	Pajarito	site	yes	1755252.105	1646963.683	surface water	128	E/I	NM-128.A_08	63	
Pajarito above Starmers	E241	E241	Pajarito	Pajarito	site	yes	1768103.439	1614687.844	surface water	128	E/I	NM-128.A_07	38	
Pajarito above Threemile	E245.5	E245.5	Pajarito	Pajarito	site	yes	1763183.035	1633089.654	surface water	128	E/I	NM-128.A_08	38	
Pajarito above Twomile	E243	E243	Pajarito	Pajarito	site	yes	1766185.42	1625793.513	surface water	128	E/I	NM-128.A_06	148	
Potrillo above SR-4	E267	E267	Water	Potrillo	site	yes	1751323.246	1645352.039	surface water	128	E/I	NM-128.A_09	197	
Pueblo below GCS	E060.1	E060.1	Pueblo	Pueblo	site	no	1772289.42	1650902.66	surface water	128	E/I	NM-99.A_001	612	
E059.5 Pueblo below LAC WWTF	E059.5	E059.5	Pueblo	Pueblo	site	no	1776062.519	1643469.866	surface water	98	intermittent	NM-99.A_001	13	EDW
E059.8 Pueblo Below Wetlands	E059.8	E059.8	Pueblo	Pueblo	site	no	1774623.8	1647376.832	surface water	98	intermittent	NM-99.A_001	85	EDW
Pueblo above Acid	E055	E055	Pueblo	Pueblo	site	no	1778877.63	1624411.282	surface water	98	intermittent	NM-97.A_002	3	
Sandia above Firing Range	E124	E124	Sandia	Sandia	site	no	1770215.618	1636600.69	surface water	128	E/I	NM-128.A_11	194	
Sandia above SR-4	E125	E125	Sandia	Sandia	site	no	1767966.131	1647472.056	surface water	128	E/I	NM-128.A_11	15	

Location ID	Location ID Alias	Windward ID	Major Watershed	Minor Watershed	Landscape	Fire-affected Watershed	Y Axis	X Axis	Water Type	NMAC Class	Hydrology (E/I/P)	Nearest AU	Nearest AU Distance (ft)	Notes
Sandia below Wetlands	E123	E123	Sandia	Sandia	site	no	1773067.617	1622687.147	surface water	126	perennial	NM-9000.A_047	83	EDW, AU delineation begins downstream
Sandia left fork at Asph Plant	E122	E122.LFat AP	Sandia	Sandia	site	no	1773922.43	1620119.01	surface water	126	perennial	NM-9000.A_063	1,577	EDW, AU delineation begins downstream
Sandia right fork at Pwr Plant	E121	E121	Sandia	Sandia	site	no	1773840.385	1620124.03	surface water	126	perennial	NM-9000.A_063	1,659	EDW, AU delineation begins downstream
South Fork of Sandia at E122		E122.SF	Sandia	Sandia	site	no	1773924.5	1620114.1	surface water	126	perennial	NM-9000.A_063	1,575	EDW, AU delineation begins downstream
Starmers above Pajarito	E242	E242	Pajarito	Starmers	site	yes	1767983.726	1614644.252	surface water	128	E/I	NM-126.A_01	7	
Ten site above Mortandad	E201.5	E201.5	Mortandad	Tensite	site	no	1768470.302	1633024.952	surface water	128	E/I	NM-128.A_17	5	
Twomile above Pajarito	E244	E244	Pajarito	Twomile	site	yes	1766733.695	1626782.28	surface water	128	E/I	NM-128.A_15	68	
Water below SR-4	E265	E265	Water	Water	site	yes	1748258.527	1642753.28	surface water	128	E/I	NM-128.A_13	12	
Rio de los Frijoles at Band	E350	E350	Frijoles	Frijoles	undeveloped	yes	1738080.2	1634678.6	surface water	121	perennial	NM-2118.A_70	21	
Los Alamos below Ice Rink	E026	E026	Los Alamos	Los Alamos	undeveloped	yes	1775624.331	1618215.135	surface water	128	E/I	NM-9000.A_063	33	
Pajarito below SR-501	E240	E240	Pajarito	Pajarito	undeveloped	yes	1770945.505	1610350.084	surface water	128	E/I	NM-128.A_07	87	
BAND-REF-3	BAND-REF-3 at RF15BAND03	BAND-REF-3	Frijoles	Frijoles	undeveloped	yes	1757405.797	1608295.878	surface water	98	intermittent	NM-126.A_03	2,362	small trib to Frijoles mainstem AU
BAND-REF-4	BAND-REF-4 at RF15BAND04	BAND-REF-4	Frijoles	Frijoles	undeveloped	yes	1755871.917	1619402.965	surface water	98	intermittent	NM-128.A_13	1,177	small trib to Frijoles mainstem AU
SEP-REF-BM1 at RF17BM01		SEP-REF-BM1	Frijoles	Frijoles	undeveloped	yes	1754660.819	1615636.458	surface water	98	intermittent	NM-128.A_13	3,736	small trib to Frijoles mainstem AU
SEP-REF-P1 at RF17P01		SEP-REF-P1	Frijoles	Frijoles	undeveloped	yes	1756279.877	1609944.04	surface water	98	intermittent	NM-126.A_03	3,018	small trib to Frijoles mainstem AU
RF09GU02	GUAJE-REF-2	GUAJE-REF-2	Los Alamos	Guaje	undeveloped	yes	1790296.6	1642533.5	surface water	98	intermittent	NM-9000.A_005	10	
SEP-REF-SJM1 at RF17SJM01		SEP-REF-SJM1	Jemez River	Jemez River	undeveloped	no	1728030.12	1520615.217	surface water	98	intermittent	NM-2105.5_10	13,879	small trib to distant Jemez River AU
SEP-REF-SJM4 at RF17SJM04		SEP-REF-SJM4	Jemez River	Jemez River	undeveloped	no	1723545.512	1524751.695	surface water	98	intermittent	NM-2105.5_21	8,722	small trib to distant Jemez River AU
WR-REF-3 at RF13WR03	172 Meadow Lane	WR-REF-3	Mortandad	Mortandad	undeveloped	no	1757295.268	1654224.752	surface water	98	intermittent	NM-9000.A_053	1,429	small trib to Canada del Buey AU
Water above SR-501	E252	E252 up	Water	Water	undeveloped	yes	1760451.049	1607279.987	surface water	98	intermittent	NM-9000.A_052	76	

AU – assessment unit
BLM – biotic ligand model
DOE – Department of Energy
E – ephemeral
EDW – effluent-dominated water
I – intermittent
ID – identification
LANL – Los Alamos National Laboratory
NMAC – New Mexico Administrative Code
NMED – New Mexico Environment Department
P – perennial
Windward – Windward Environmental LLC
WWTF – wastewater treatment facility

4.1 DATA AGGREGATION AND EVALUATION

Initial data processing for the aggregation of BLM input data focused on summarizing analyte concentrations on the basis of a single location and date combination. As specified in Section 3.5, a requirement for BLM calculations was that a pH and DOC measurement had to be associated with a sample collected at the same location on the same day (or within a 24-hour period, or otherwise associated with a given sampling event). Among the 1,142 initial location-date pairings (i.e., events) in the BLM dataset, there were only 4 instances of pH (from a filtered sample) combined with DOC (from a filtered sample). After working through the steps specified in Section 3.5 for establishing BLM inputs, the following number of events were sequentially aggregated:

- 331 potential events total after including 227 events with pH from unfiltered samples and DOC from filtered samples
- 464 potential events after including 133 other events with representations or estimates of DOC
  - 1 event for which DOC was reported for an unfiltered sample
  - 3 events for which TOC was reported for a filtered sample
  - 129 events for which DOC was estimated from TOC
- 463 potential events after including representations of alkalinity
  - 132 events for which alkalinity was reported for a filtered sample
  - 331 events for which alkalinity was reported for an unfiltered sample
  - 1 event for which alkalinity was not reported
- 457 potential events after considering major cations
  - 6 events did not have concentration data for calcium, magnesium, sodium, and potassium
- 457 potential events after considering major anions
  - 4 events lacked sulfate concentrations, but those were estimated using location-specific averages
  - 5 events lacked chloride concentrations, but those were estimated using location-specific averages

Because estimation of DOC from TOC was necessary for 129 events, a comparison of DOC and TOC in samples for which both analytes were measured was performed (Figure 4-1). The conversion factor of 0.86 used to estimate DOC from TOC was taken as the lower 95% confidence limit for the slope of the relationship between DOC and TOC (e.g., green line in Figure 4-1). This approach and TOC to DOC conversion factor were very similar to that (0.83) used by Oregon Department of Environmental Quality in its copper BLM-based IWQC implementation guidance (ODEQ 2016a). In addition, a ceiling of 29.65 mg/L was used for DOC inputs to the BLM where reported or estimated DOC were greater than this upper bound of the calibration range specified in BLM user's guides (HydroQual 2007; Windward 2017).

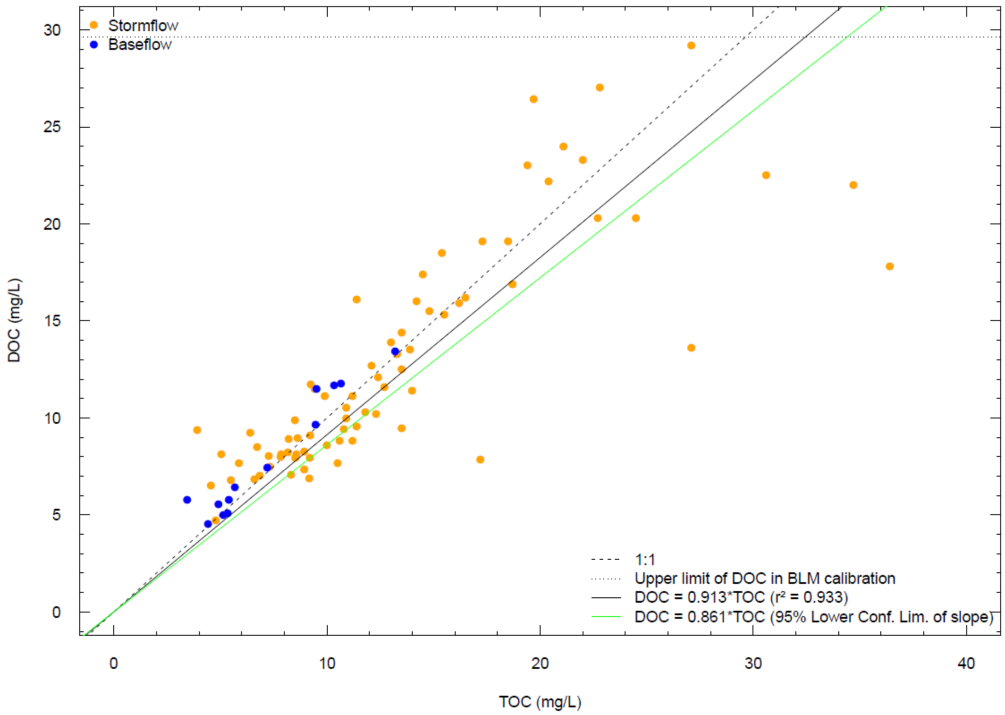


Figure 4-1.Relationship between DOC and TOC

Similarly, alkalinity from unfiltered samples was used as a substitute for missing dissolved alkalinity inputs. The relationship between filtered and unfiltered alkalinity from events for which both were measured, indicated that substitution of alkalinity from unfiltered samples provided a reasonable estimate of alkalinity in filtered samples (Figure 4-2).

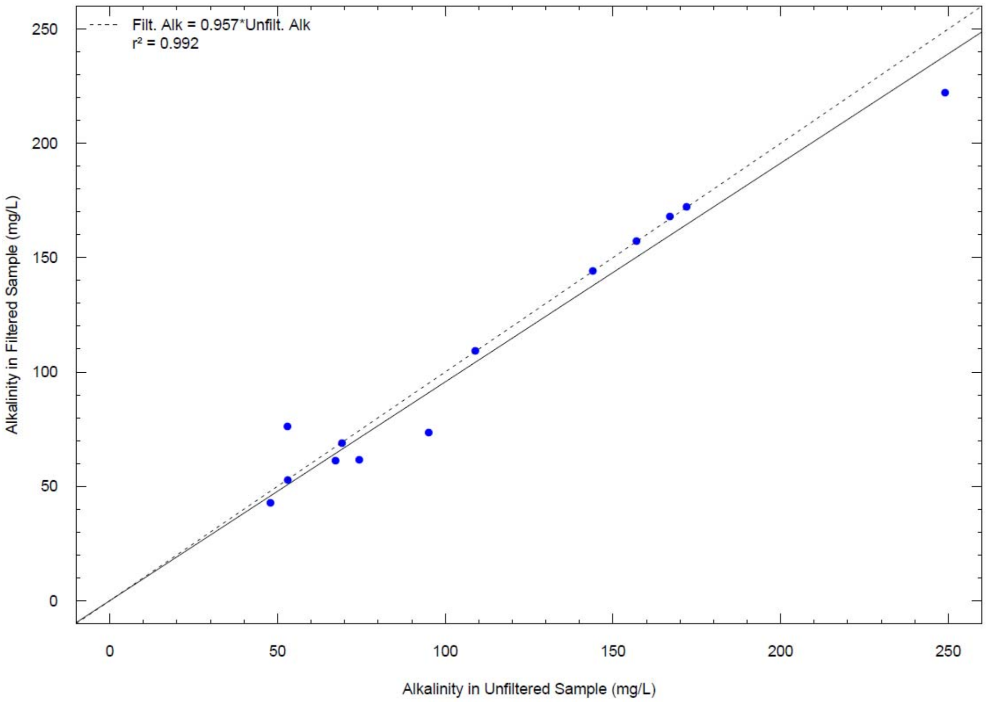


Figure 4-2. Relationship between alkalinity in filtered samples and alkalinity in unfiltered samples

Six potential BLM sample datasets lacked data for major cations, and were not considered further. Of the 457 remaining potential BLM events, 4 lacked sulfate concentrations and 5 lacked chloride concentrations. Because the purpose of these BLM inputs is to help satisfy charge balance, and because aluminum, copper, lead, and zinc BLM calculations are not sensitive to these inputs, location average concentrations were used to fill these data gaps.

No surface water data existed for temperature in the dataset considered herein, so a temperature sensitivity analysis was conducted across the BLM calibration range of 10 to 25°C. See Figure 4-3. The differences in BLM-based acute aluminum IWQC computed across the 10-25°C range varied little for copper, lead and zinc. For aluminum, the figure shows that BLM-based WQC differences were inversely proportional to temperature, with marked differences across the range, which was not unexpected given the known sensitivity of the aluminum BLM to temperature. Based on these results, a conservative assumption of 10°C was deemed appropriate (it is the lower bound of the BLM calibration range for temperature). The water temperature variable is not included in the MLR proposed by EPA in its 2017 draft aluminum AWQC, so if such AWQC are eventually adopted, the temperature sensitivity issue for aluminum appears to be moot for the MLR-based AWQC.

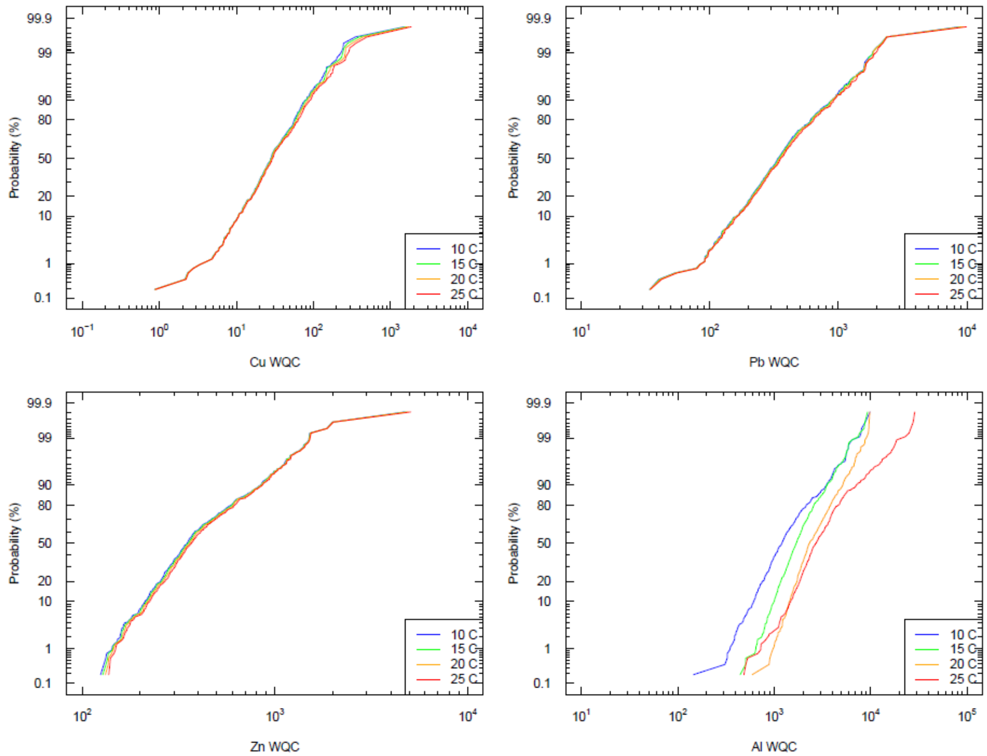


Figure 4-3. Temperature sensitivity analysis for copper, lead, zinc and aluminum BLMs

After the above considerations, the resulting dataset contained sufficient information to perform BLM calculations for 457 events. Table 4-2[10] provides a complete summary of all water sampling events considered when evaluating potential complete BLM datasets (i.e., 464 events). The detection status (i.e., "<," a value reported below the concentration indicated) and sources of any data substitutions are also indicated in Table 4-2. None of the BLM inputs were affected by detection limitations. A summary of the number of BLM events associated with each location is provided in Table 4-3, and a general spatial distribution of data richness is shown in Figure 4-4 (see Plate 1 for the geographic map of locations).

Table 4-2. LANL Surface Water Dataset for BLM Evaluations

(provided electronically in a separate Microsoft® Excel document)

[10] Table 4-2 is provided electronically in a separate Microsoft® Excel document.

Table 4-3. Summary of complete BLM events by location

Location ID	Windward ID	Major Watershed	Minor Watershed	Landscape	Sample Type[a]	Events with Both pH and DOC			Events with Complete BLM Information		
						N	Min. Date	Max. Date	N	Min. Date	Max. Date
Ancho below SR-4	E275	Ancho	Ancho	site	WT	3	7/25/2013	6/25/2017	3	7/25/2013	6/25/2017
Chaquehui at TA-33	E338	Chaquehui	Chaquehui	site	WT	2	9/13/2013	7/23/2014	2	9/13/2013	7/23/2014
DP above Los Alamos Canyon	E040	Los Alamos	DP	site	WT	20	8/5/2013	9/28/2017	20	8/5/2013	9/28/2017
DP above TA-21	E038	Los Alamos	DP	site	WS, WT	25	9/2/2008	8/7/2017	25	9/2/2008	8/7/2017
DP below grade ctrl structure	E039.1	Los Alamos	DP	site	WT, WT+WS	26	6/14/2013	8/7/2017	26	6/14/2013	8/7/2017
Guaje at SR-502	E099	Los Alamos	Guaje	site	WT	1	8/5/2013	8/5/2013	1	8/5/2013	8/5/2013
Los Alamos above DP Canyon	E030	Los Alamos	Los Alamos	site	WM, WS, WT	4	4/28/2005	10/4/2017	4	4/28/2005	10/4/2017
Los Alamos above low-head weir	E042.1	Los Alamos	Los Alamos	site	WT	16	7/12/2013	10/4/2017	16	7/12/2013	10/4/2017
Los Alamos above Rio Grande	E1099	Los Alamos	Los Alamos	site	WT	4	7/25/2013	9/12/2013	4	7/25/2013	9/12/2013
Los Alamos below low-head weir	E050.1	Los Alamos	Los Alamos	site	WT	18	7/12/2013	10/5/2017	18	7/12/2013	10/5/2017
Mortandad above Ten Site	E201	Mortandad	Mortandad	site	WT	4	7/12/2013	7/31/2014	4	7/12/2013	7/31/2014
Mortandad at LANL Boundary	E204	Mortandad	Mortandad	site	WT	2	7/31/2014	10/4/2017	1	7/31/2014	7/31/2014
Mortandad below Effluent Canon	E200	Mortandad	Mortandad	site	WS, WP, WT	13	4/29/2005	10/4/2017	13	4/29/2005	10/4/2017
Ten Site above Mortandad	E201.5	Mortandad	Tensite	site	WT	1	9/13/2013	9/13/2013	1	9/13/2013	9/13/2013
La Delfe above Pajarito	E242.5	Pajarito	Arroyo de la Delfe	site	WT	4	7/20/2015	10/5/2017	4	7/20/2015	10/5/2017
Pajarito above SR-4	E250	Pajarito	Pajarito	site	WT	3	9/13/2013	7/21/2015	3	9/13/2013	7/21/2015
Pajarito above Starmers	E241	Pajarito	Pajarito	site	WT	2	7/15/2015	7/20/2015	2	7/15/2015	7/20/2015
Pajarito above Threemile	E245.5	Pajarito	Pajarito	site	WT	15	7/12/2013	10/5/2017	15	7/12/2013	10/5/2017

Location ID	Windward ID	Major Watershed	Minor Watershed	Landscape	Sample Type[a]	Events with Both pH and DOC			Events with Complete BLM Information		
						N	Min. Date	Max. Date	N	Min. Date	Max. Date
Pajarito above Twomile	E243	Pajarito	Pajarito	site	WP, WS, WT	12	8/29/2006	7/20/2015	12	8/29/2006	7/20/2015
Starmers above Pajarito	E242	Pajarito	Starmers	site	WT	3	7/6/2015	9/28/2017	3	7/6/2015	9/28/2017
Twomile above Pajarito	E244	Pajarito	Twomile	site	WP, WS, WT	14	8/29/2006	10/4/2017	14	8/29/2006	10/4/2017
Acid above Pueblo	E056	Pueblo	Acid	site	WT, WS, WP, WS+WT	21	5/3/2005	8/23/2017	21	5/3/2005	8/23/2017
South Fork of Acid Canyon	E055.5	Pueblo	Acid	site	WT	7	9/13/2013	7/29/2017	7	9/13/2013	7/29/2017
E059.5 Pueblo below LAC WWTF	E059.5	Pueblo	Pueblo	site	WT	5	7/29/2014	9/29/2017	5	7/29/2014	9/29/2017
E059.8 Pueblo Below Wetlands	E059.8	Pueblo	Pueblo	site	WT	3	10/21/2015	10/5/2017	3	10/21/2015	10/5/2017
Pueblo above Acid	E055	Pueblo	Pueblo	site	WT, WP, WS	14	5/3/2005	9/29/2017	14	5/3/2005	9/29/2017
Pueblo below GCS	E060.1	Pueblo	Pueblo	site	WT	2	7/2/2015	7/20/2015	2	7/2/2015	7/20/2015
Sandia above Firing Range	E124	Sandia	Sandia	site	WT	5	7/29/2014	9/29/2017	5	7/29/2014	9/29/2017
Sandia above SR-4	E125	Sandia	Sandia	site	WT	2	9/13/2013	7/31/2014	2	9/13/2013	7/31/2014
Sandia below Wetlands	E123	Sandia	Sandia	site	WP, WS, WT, WT+WS	49	7/12/2006	8/10/2017	48	7/12/2006	8/10/2017
Sandia left fork at Asph Plant	E122.LFatAP	Sandia	Sandia	site	WT	11	9/12/2013	8/21/2017	11	9/12/2013	8/21/2017
Sandia right fork at Pwr Plant	E121	Sandia	Sandia	site	WS, WT	47	11/3/2008	8/10/2017	46	11/3/2008	8/10/2017
South Fork of Sandia at E122	E122.SF	Sandia	Sandia	site	WS+WP, WP, WS	24	6/29/2006	8/10/2017	22	6/29/2006	8/10/2017
Canon de Valle below MDA P	E256	Water	Cañon de Valle	site	WP, WS, WT	19	1/29/2007	6/2/2017	19	1/29/2007	6/2/2017
Potrillo above SR-4	E267	Water	Potrillo	site	WT	1	7/2/2014	7/2/2014	1	7/2/2014	7/2/2014

Location ID	Windward ID	Major Watershed	Minor Watershed	Landscape	Sample Type[a]	Events with Both pH and DOC			Events with Complete BLM Information		
						N	Min. Date	Max. Date	N	Min. Date	Max. Date
Water below SR-4	E265	Water	Water	site	WT	3	9/13/2013	8/1/2015	3	9/13/2013	8/1/2015
BAND-REF-3	BAND-REF-3	Frijoles	Frijoles	undeveloped	WT	2	9/9/2015	10/20/2015	2	9/9/2015	10/20/2015
BAND-REF-4	BAND-REF-4	Frijoles	Frijoles	undeveloped	WT	1	10/20/2015	10/20/2015	1	10/20/2015	10/20/2015
Rio de los Frijoles at Band	E350	Frijoles	Frijoles	undeveloped	WP, WS, WT	8	9/20/2006	10/22/2015	8	9/20/2006	10/22/2015
SEP-REF-BM1 at RF17BM01	SEP-REF-BM1	Frijoles	Frijoles	undeveloped	WT	4	9/27/2017	10/5/2017	2	9/27/2017	9/28/2017
SEP-REF-P1 at RF17P01	SEP-REF-P1	Frijoles	Frijoles	undeveloped	WT	4	9/27/2017	10/5/2017	4	9/27/2017	10/5/2017
SEP-REF-SJM1 at RF17SJM01	SEP-REF-SJM1	Jemez River	Jemez River	undeveloped	WT	4	9/26/2017	10/4/2017	4	9/26/2017	10/4/2017
SEP-REF-SJM4 at RF17SJM04	SEP-REF-SJM4	Jemez River	Jemez River	undeveloped	WT	2	8/24/2017	9/27/2017	2	8/24/2017	9/27/2017
RF09GU02	GUAJE-REF-2	Los Alamos	Guaje	undeveloped	WT	3	7/29/2015	8/17/2015	3	7/29/2015	8/17/2015
Los Alamos below Ice Rink	E026	Los Alamos	Los Alamos	undeveloped	WM, WS, WT	4	4/29/2005	8/3/2016	4	4/29/2005	8/3/2016
WR-REF-3 at RF13WR03	WR-REF-3	Mortandad	Mortandad	undeveloped	WT	6	9/11/2013	8/27/2015	6	9/11/2013	8/27/2015
Pajarito below SR-501	E240	Pajarito	Pajarito	undeveloped	WT	9	8/20/2013	7/15/2015	9	8/20/2013	7/15/2015
Water above SR-501	E252 up	Water	Water	undeveloped	WP, WS, WT	12	1/24/2007	9/19/2013	12	1/24/2007	9/19/2013

[a] Sample types separated by a plus sign (i.e., "+") indicate that the specified sample types were associated with a single event at the specified location.

BLM – biotic ligand model
DOC – dissolved organic carbon
ID – identification
LANL – Los Alamos National Laboratory
WM – snowmelt
WP – persistent water
WS – surface water
WT – storm water
Windward – Windward Environmental LLC
WWTF – wastewater treatment facility

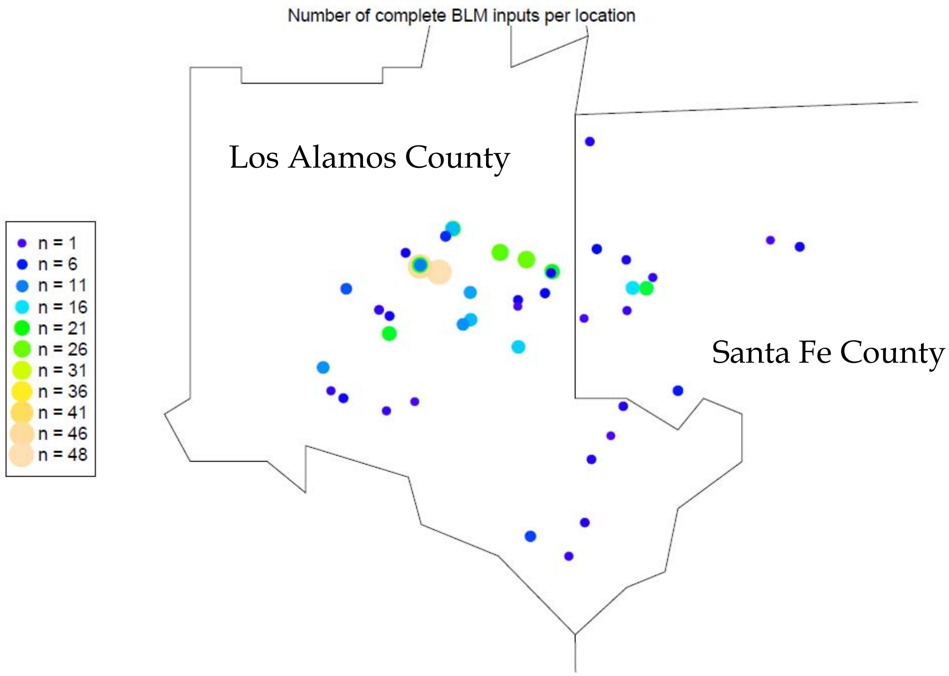


Figure 4-4. General spatial distribution of locations and data richness for BLM inputs (LANL dataset)

For the 457 events for which BLM calculations could be performed (i.e., the BLM dataset):

- 433 events had measured dissolved copper
- 446 events had measured dissolved lead and zinc
- 370 events had measured total (unfiltered) aluminum
- 150 events had measured 10-µm filtered aluminum
- 34 events had measured 1-µm filtered aluminum
- 457 events had measured dissolved (0.45-µm filtered) aluminum.

These large datasets of concurrent metal and IWQC indicate that a rich set of TUs can be calculated for the evaluation of decision errors using each WQC approach. The opportunities for calculating FMBs depends on the richness and variability of TUs and IWQCs at locations of interest (discrete and aggregated spatially). However, in these cases, the TUs will be uncertain when affected by metals results that were reported as below detection limits. For purposes of calculating TUs in these cases, the reported detection limit was used, rather than a typical basis of using ½ the detection limit[11].

[11] Using the full detection limit was done to be conservative when comparing metal concentrations directly to IWQC and to flag any TUs affected by non-detects. The maximum likelihood estimation

Potentially fire-affected datasets were identified by LANL staff as occurring during the period Jul 4, 2011 through December 31, 2013 for particular watersheds affected by wildfires. The fire-affected watersheds are identified in Table 4-1. The IWQC based on sample data for locations and periods that may be potentially affected by wildfires are plotted as a separate data series in scatter plots presented in subsequent sections and appendices.

Lastly, the supplemental NWQMC dataset for the Rio Grande (Figure 4-5) included 78 BLM events for 5 different locations (e.g., near Taos, at Otowi Bridge, below Cochiti Dam, at San Felipe, and below Alameda Bridge). All BLM inputs for the NWQMC dataset, including temperature, were measured values (i.e., estimates or substitutions were not considered), with the exception of %HA, which was assumed to be 10%, consistent with all other BLM calculations herein.

4.2 APPLICATION OF BLMS FOR GENERATING IWQC

Acute BLMs were applied to the BLM dataset to derive acute IWQCs for copper, lead, and zinc using the BLMs described by EPA (2007), DeForest et al. (2017), and DeForest and Van Genderen (2012), respectively. In addition to BLM-based IWQC for these events, hardness-based IWQC were calculated using the measured hardness result and the relevant hardness-based equation for each metal's AWQC described in NMAC.20.6.4.900(I). All IWQC outcomes for the LANL dataset are provided in Table 4-2 (see columns to the right of the water quality dataset).

For aluminum, as noted in Section 3.5, the currently available BLM is limited to generating chronic IWQC. Consequently, the following process was used to generate preliminary acute aluminum BLM-based IWQC. First, the aluminum BLM (Santore et al. 2018) was applied to the BLM dataset to generate chronic aluminum IWQCs. Then, the chronic IWQCs were converted to acute IWQCs by multiplying each chronic BLM result by an ACR of 5.0. This ACR approach is often used by EPA, although most often in the converse situation (i.e., when deriving chronic criteria from acute toxicity datasets) (EPA 1985). In the recent draft WQC document for aluminum, EPA (2017) calculated a final ACR of 8.068, but the ACR is generally intended to convert a final acute value (FAV) to a final chronic value (or chronic criterion). Using the lowest genus mean chronic value for *Salmo* (508.5 µg/L) and the FAV of 2741 µg/L described in a scenario by EPA (2017), a conservative ACR would be 2741/508.5 = 5.39. For added conservatism here, calculation of preliminary aluminum acute BLM-based IWQCs used an ACR of 5.0. Further evaluations of the overall situation for aluminum are underway as part of other LANL efforts in collaboration with the NMED SWQB.

(MLE) technique used in FMB calculations accounts for censored (i.e., non-detect) data, and properly handles them when fitting distributions. When fitting distributions, this approach is generally favored over substitution (i.e., fabrication) approaches.

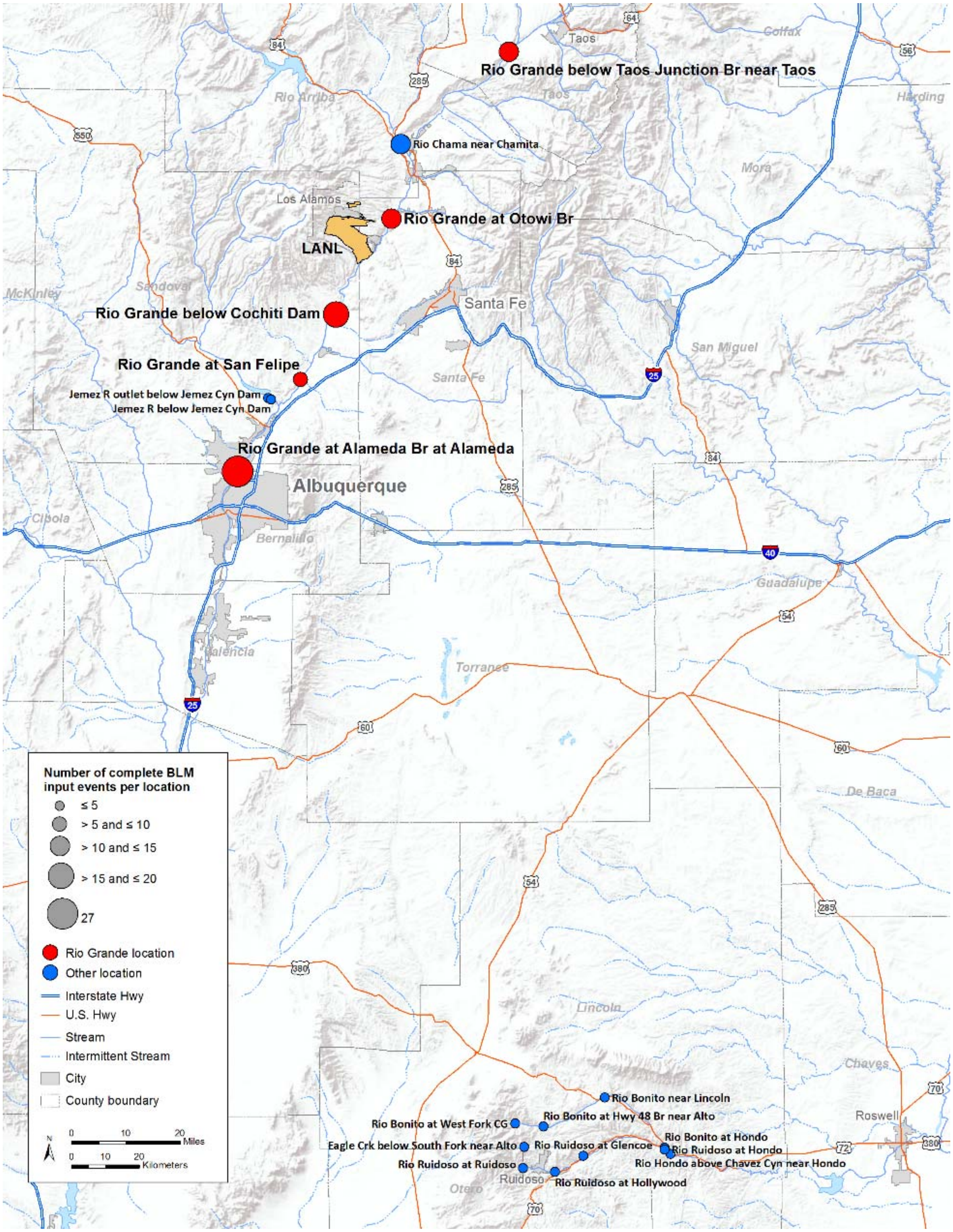


Figure 4-5. Spatial distribution of locations and data richness for BLM inputs from New Mexico locations in NWQMC dataset

4.3 OVERALL COMPARISONS OF BLM-BASED AND HARDNESS-BASED ACUTE IWQC

Comparisons of acute BLM- and hardness-based TUs for dissolved copper, lead, and zinc are shown in Figures 4-6 to 4-8 based on BLM input data for all locations and BLM events. Referring to Figure 3-1 aids interpretation of the magnitude and frequency of potential false positives and false negatives where the hardness-based IWQC were over- and under-conservative, respectively, with respect to BLM-based IWQC.

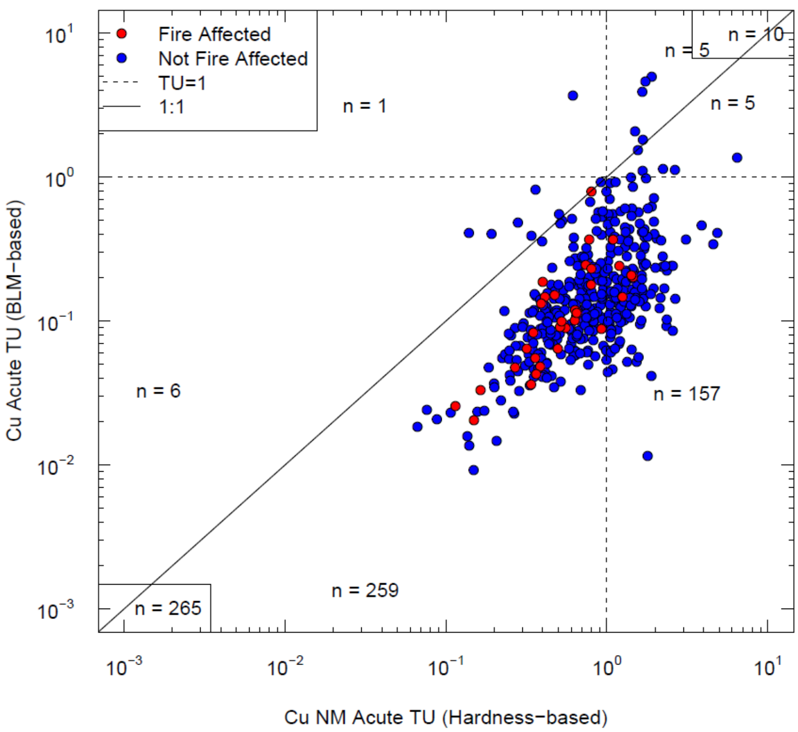


Figure 4-6. Comparison of acute <u>dissolved copper</u> IWQC TUs between EPA 2007 BLM and New Mexico hardness-based AWQC

For copper, Figure 4-6 shows that the hardness-based AWQC for copper frequently generated false positives, i.e., the 157 TU values plotted in the lower right quadrant indicate that the observed dissolved copper concentrations would exceed the New Mexico IWQC in 36% of the events, but would not exceed BLM-based IWQC. Meanwhile, application of the BLM identified one false negative, where the observed copper would exceed acute BLM-based IWQC but not the hardness-based IWQC. In the upper right, Figure 4-6 shows that the BLM and the New Mexico copper IWQC yield a consistent determination of a true exceedance in 2% (10) of the events and a true non-exceedance in 61% (265) of the events in the lower left.

For lead, Figure 4-7 shows that the BLM and New Mexico IWQC returned equivocal results (all observed concentrations did not exceed either basis) without decision errors, yet the New Mexico IWQC tended to return higher TUs than did the BLM-based IWQC (data points clustering further to the right and lower than the 1:1 line of perfect equivalency). For zinc (Figure 4-8), a similar pattern occurred, except only 2% (11) of the hardness-based IWQC TUs were false positives relative to BLM-based IWQC.

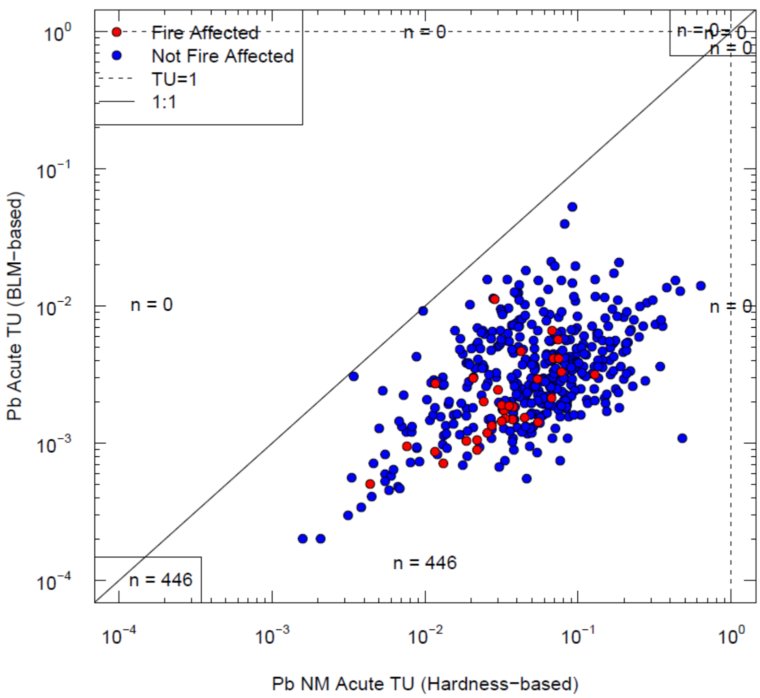


Figure 4-7.Comparison of acute <u>dissolved lead</u> IWQC TUs between BLM and New Mexico hardness-based AWQC

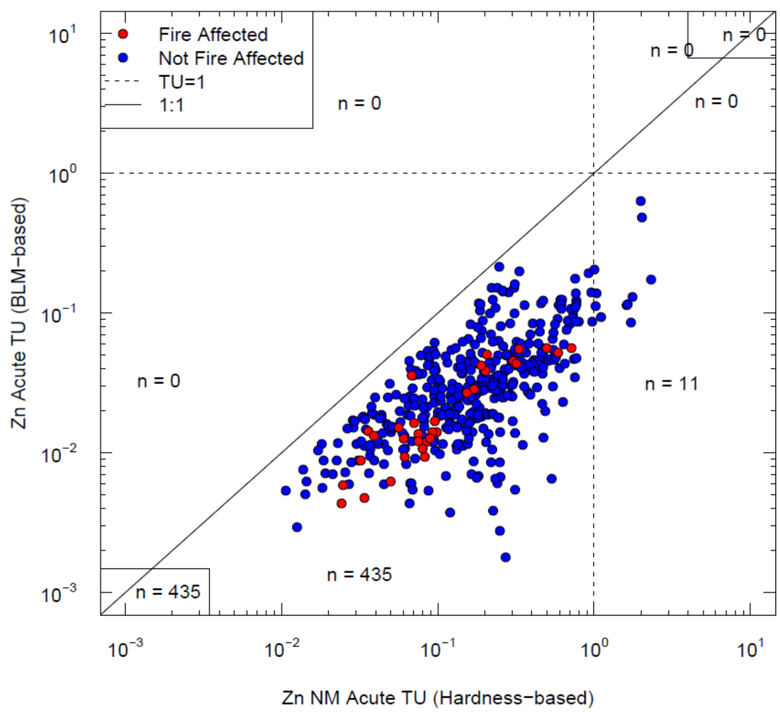


Figure 4-8. Comparison of acute dissolved zinc IWQC TUs between BLM and New Mexico hardness-based AWQC

For aluminum, the acute BLM- and hardness-based IWQC TU comparisons are shown in Figures 4-9 to 4-12 for unfiltered-, 10-µm-, 1-µm, and 0.45-µm-filtered aluminum concentrations. Similarly, comparisons of EPA draft MLR- and hardness-based acute TUs are shown for unfiltered-, 10-µm-, 1-µm, and 0.45-µm-filtered aluminum concentrations in Figures 4-13 to 4-16. Overall for aluminum, interpreting the patterns is complicated and subjective given the current uncertainty of 1) the sample filter preparation issue,[12] 2) the BLM and MLR basis of acute IWQC, and 3) implications of natural background[13] concentrations that are likely false positives (i.e., fine mineral forms of aluminum that are not bioavailable but that are included in the filtrates from all three sample filter sizes, which LANL has shown to be the case for 1-µm filtrates (LANL 2018b)). Thus, characterizing potential decision error rates at this time may be premature.

[12] Current NMED guidance calls for analyzing "total" aluminum in filtrate from a 10-µm filter if turbidity is above 30 nephelometric turbidity units (NTU) (NMED 2012a, 2013, 2015). LANL staff and NMED have been discussing the problems that are apparent when using filters larger than 0.45-µm for aluminum analysis (i.e. the risk of significant false positive bias via inclusion of fine mineral forms of aluminum that are non-toxic) (LANL 2018b, 2016). Further evaluations are being planned by Windward and LANL staff in collaboration with NMED (95% draft toxicity testing plan).

[13] LANL has completed extensive data collection and characterization demonstrating significantly elevated natural background concentrations of aluminum and other constituents in storm water samples collected from various surface waters within and around LANL in the vicinity of the Pajarito Plateau (LANL 2007, 2010b, 2013, 2014, 2015).

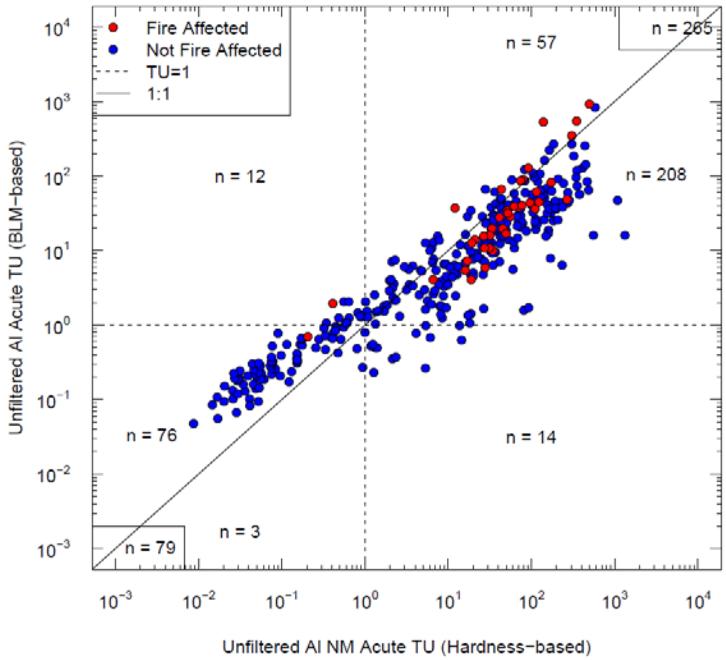


Figure 4-9. Comparison of acute aluminum IWQC TUs between BLM and New Mexico hardness-based AWQC (on basis of unfiltered aluminum)

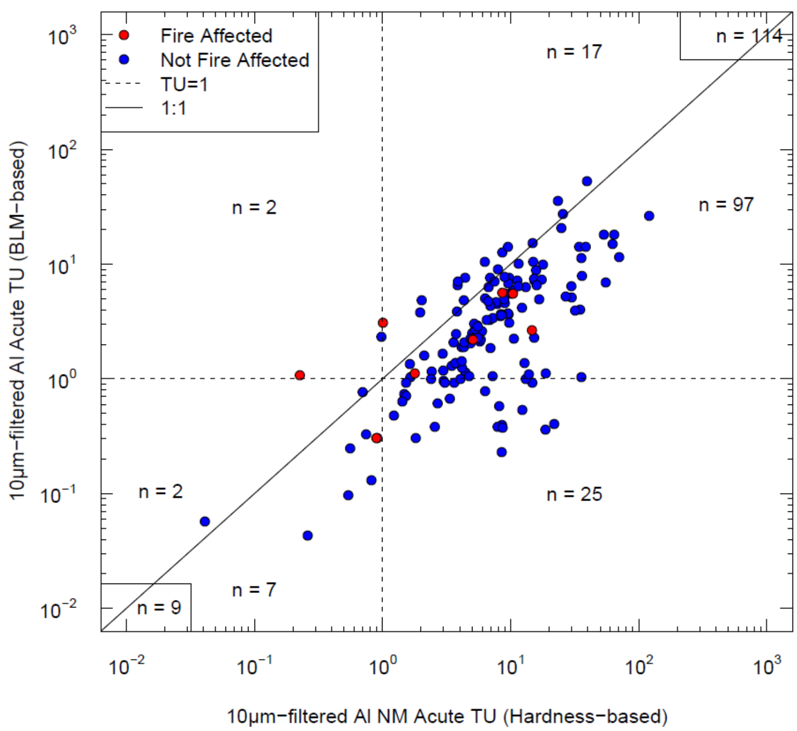


Figure 4-10. Comparison of acute aluminum IWQC TUs between BLM and New Mexico hardness-based AWQC (on basis of 10-µm filtered aluminum)

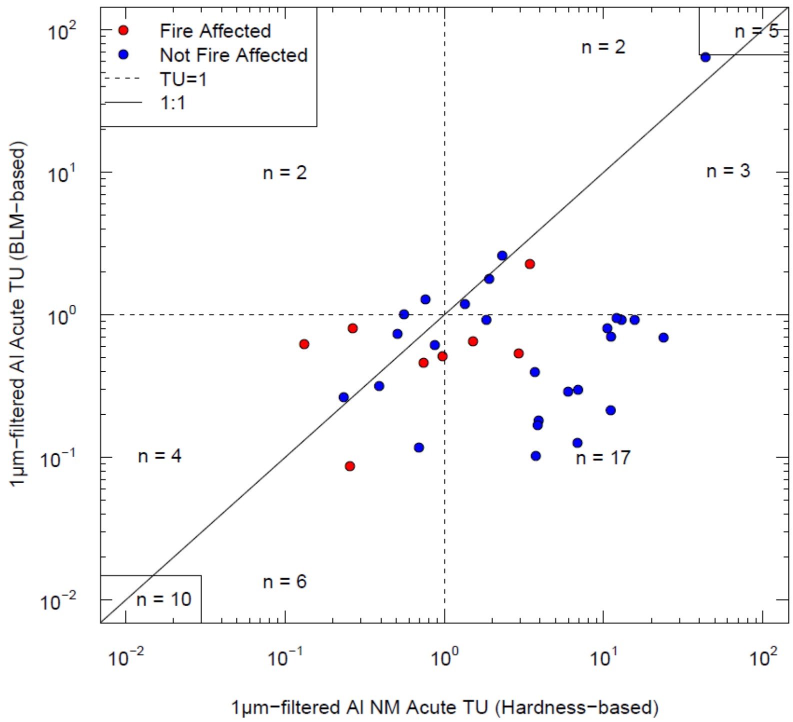


Figure 4-11. Comparison of acute <u>aluminum</u> IWQC TUs between BLM and New Mexico hardness-based AWQC (on basis of <u>1-µm filtered</u> aluminum)

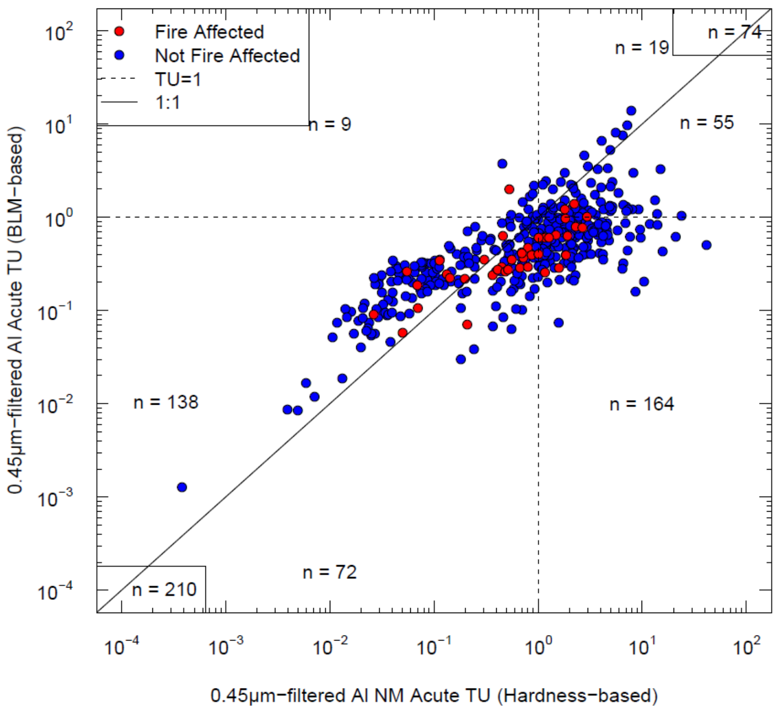


Figure 4-12. Comparison of acute <u>aluminum</u> IWQC TUs between BLM and New Mexico hardness-based AWQC (on basis of <u>0.45 µm filtered</u> aluminum)

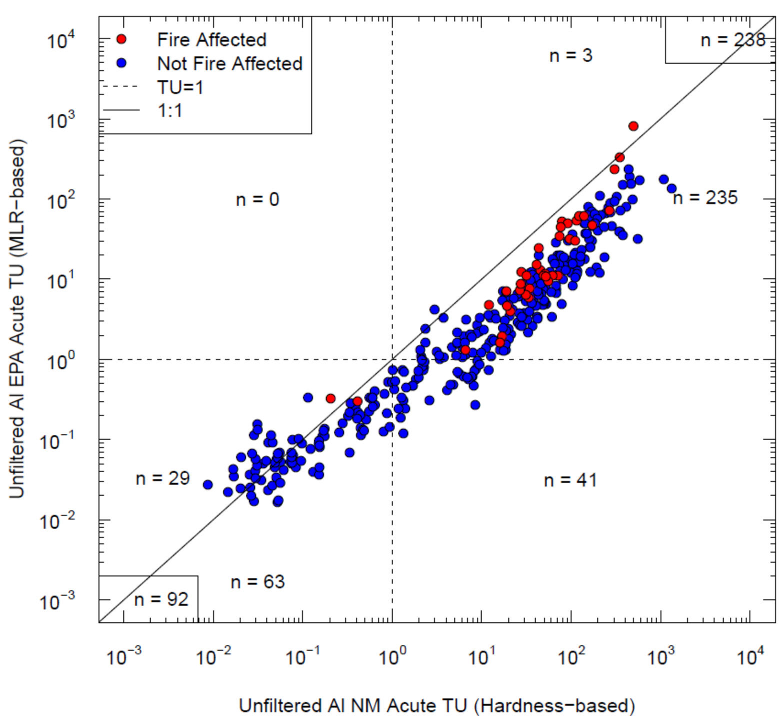


Figure 4-13. Comparison of EPA draft <u>MLR-based</u> acute TUs and New Mexico hardness-based TUs for aluminum (for <u>unfiltered</u> aluminum)

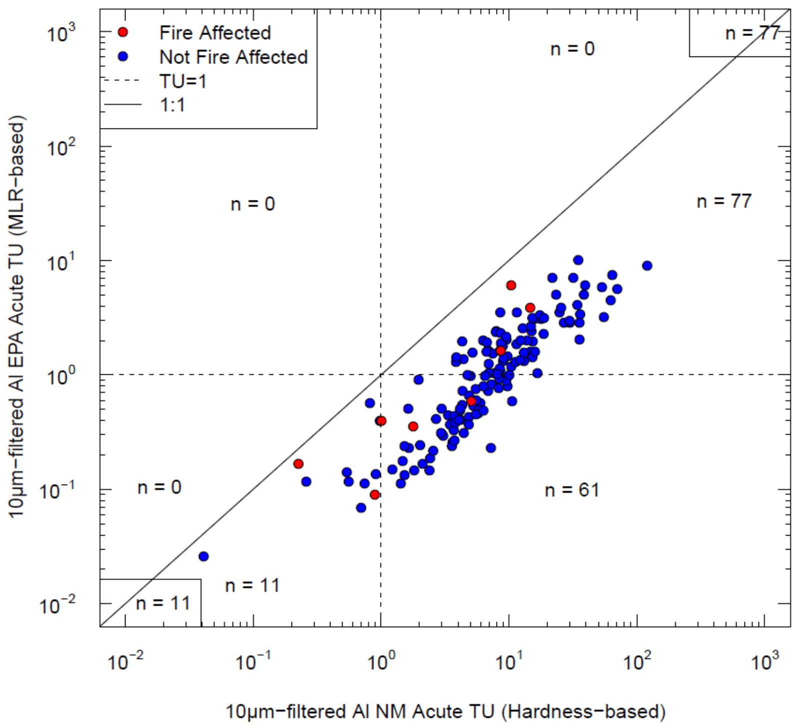


Figure 4-14. Comparison of EPA draft MLR-based acute TUs and New Mexico hardness-based TUs for aluminum (for 10-µm filtered aluminum)

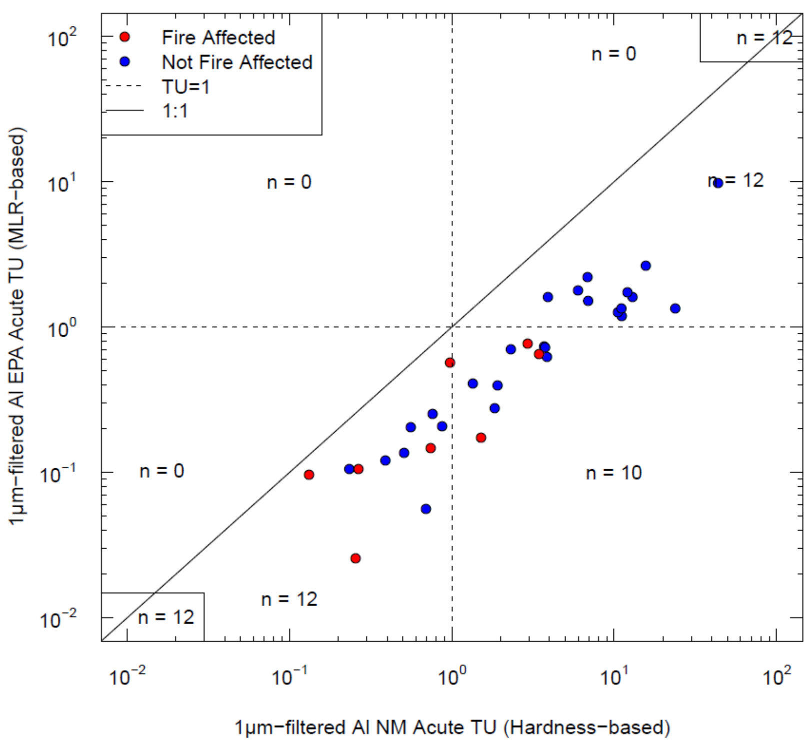


Figure 4-15. Comparison of EPA draft MLR-based acute TUs and New Mexico hardness-based TUs for aluminum (for 1-µm filtered aluminum)

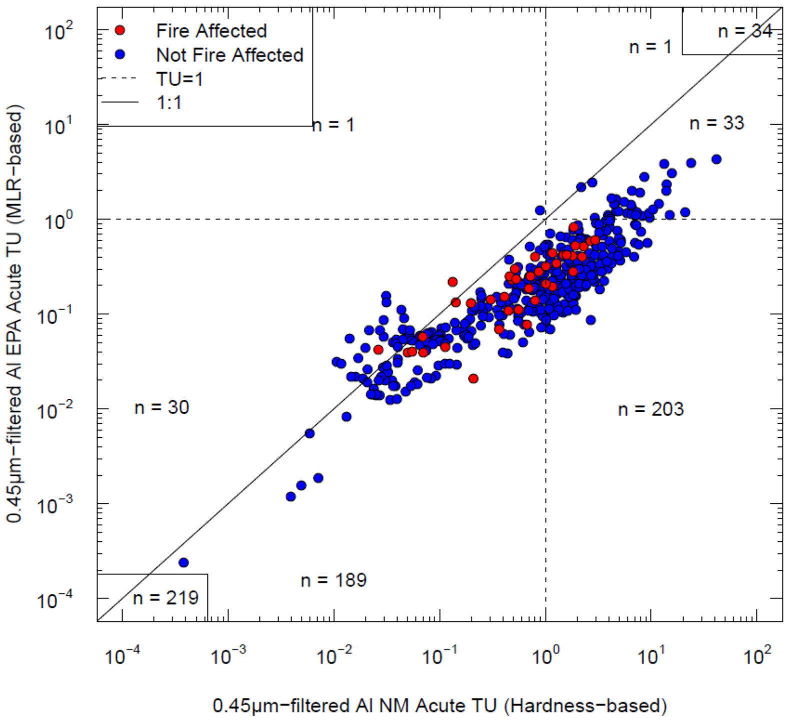


Figure 4-16. Comparison of EPA draft <u>MLR-based</u> acute TUs and New Mexico (2010; AWQC) hardness-based TUs for aluminum (for <u>0.45-µm filtered</u> aluminum)

Table 4-4 provides a summary of acute BLM-based TUs for each location (i.e., description of percentage of TUs>1, number of TUs calculated, number of TUs affected by BDL metal concentrations, and number BDL-affected TUs>1). On the basis of acute BLM-based IWQC, there were no TUs > 1 for lead and zinc.

Table 4-4. Summary of acute BLM-based TUs by location

Location ID	Windward ID	Unfiltered Aluminum				10-µm Filtered Aluminum				1-µm Filtered Aluminum				0.45-µm Filtered Aluminum				0.45-µm Filtered Copper				0.45-µm Filtered Lead				0.45-µm Filtered Zinc			
			No.				No.				No.				No.				No.				No.				No.		
		% TU>1	TU	BDL	BDL TU>1	% TU>1	TU	BDL	BDL TU>1	% TU>1	TU	BDL	BDL TU>1	% TUs>1	TU	BDL	BDL TU>1	% TUs>1	TU	BDL	BDL TU>1	% TUs>1	TU	BDL	BDL TU>1	% TUs>1	TU	BDL	BDL TU>1
Acid above Pueblo	E056	88	17	1	0	100	4	0	0					24	21	2	0	**5**	20	4	**1**	0	21	5	0	0	21	1	0
Ancho below SR-4	E275	100	3	0	0									0	3	0	0	0	3	0	0	0	3	0	0	0	3	2	0
BAND-REF-3	BAND-REF-3	100	2	0	0	50	2	0	0	0	2	0	0	0	2	0	0	0	2	0	0	0	2	2	0	0	2	2	0
BAND-REF-4	BAND-REF-4	100	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	1	0	0	1	0	0
Canon de Valle below MDA P	E256	27	15	1	0	100	1	0	0					0	19	12	0	0	18	17	0	0	19	19	0	0	19	16	0
Chaquehui at TA-33	E338	100	2	0	0									0	2	0	0	0	2	0	0	0	2	0	0	0	2	1	0
DP above Los Alamos Canyon	E040	100	10	0	0	100	13	0	0					35	20	0	0	0	20	0	0	0	20	0	0	0	20	1	0
DP above TA-21	E038	94	18	0	0	91	11	0	0	50	2	0	0	20	25	1	0	0	23	1	0	0	23	9	0	0	23	4	0
DP below grade ctrl structure	E039.1	100	18	0	0	92	12	0	0					31	26	0	0	0	26	0	0	0	26	5	0	0	26	2	0
E059.5 Pueblo below LAC WWTF	E059.5	100	3	0	0	100	2	0	0					0	5	0	0	0	5	0	0	0	5	0	0	0	5	0	0
E059.8 Pueblo Below Wetlands	E059.8	0	1	0	0	0	1	0	0					0	3	0	0	0	3	0	0	0	3	1	0	0	3	0	0
Guaje at SR-502	E099	100	1	0	0									0	1	0	0	0	1	0	0	0	1	1	0	0	1	1	0
La Delfe above Pajarito	E242.5	100	2	0	0	100	2	0	0					25	4	0	0	0	4	0	0	0	4	1	0	0	4	1	0
Los Alamos above DP Canyon	E030	50	2	0	0									0	4	0	0	0	4	2	0	0	4	2	0	0	4	0	0
Los Alamos above low-head weir	E042.1	100	10	0	0	100	7	0	0					25	16	0	0	0	16	0	0	0	16	0	0	0	16	2	0
Los Alamos above Rio Grande	E1099	100	4	0	0									0	4	0	0	0	4	0	0	0	4	0	0	0	4	1	0
Los Alamos below Ice Rink	E026	67	3	0	0	100	1	0	0					0	4	0	0	0	4	2	0	0	4	3	0	0	4	2	0
Los Alamos below low-head weir	E050.1	100	17	0	0	100	8	0	0					11	18	0	0	0	18	0	0	0	18	3	0	0	18	2	0
Mortandad above Ten Site	E201	100	4	0	0									0	4	0	0	0	4	0	0	0	4	0	0	0	4	0	0
Mortandad at LANL Boundary	E204	100	1	0	0									100	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0
Mortandad below Effluent Canon	E200	70	10	0	0									46	13	0	0	0	12	0	0	0	13	8	0	0	13	1	0
Pajarito above SR-4	E250	100	3	0	0	100	1	0	0					0	3	0	0	0	3	0	0	0	3	0	0	0	3	0	0
Pajarito above Starmers	E241	100	2	0	0	100	2	0	0					0	2	0	0	0	2	1	0	0	2	1	0	0	2	1	0
Pajarito above Threemile	E245.5	100	11	0	0	100	5	0	0					33	15	0	0	0	15	0	0	0	15	4	0	0	15	3	0
Pajarito above Twomile	E243	92	12	0	0	100	2	0	0					83	12	0	0	**11**	9	6	**1**	0	12	5	0	0	12	2	0
Pajarito below SR-501	E240	100	9	0	0	50	4	0	0	0	3	0	0	11	9	0	0	0	6	1	0	0	6	0	0	0	6	1	0
Potrillo above SR-4	E267	100	1	0	0									0	1	0	0	0	1	0	0	0	1	0	0	0	1	1	0
Pueblo above Acid	E055	60	10	1	0	67	3	0	0					21	14	2	0	0	13	4	0	0	14	6	0	0	14	1	0
Pueblo below GCS	E060.1	100	2	0	0	100	2	0	0					50	2	0	0	0	2	0	0	0	2	0	0	0	2	0	0
RF09GU02	GUAJE-REF-2	100	3	0	0	100	3	0	0	100	3	0	0	0	3	0	0	0	3	0	0	0	3	1	0	0	3	1	0
Rio de los Frijoles at Band	E350	50	8	0	0	100	2	0	0	50	2	0	0	13	8	1	0	0	7	5	0	0	8	6	0	0	8	7	0
Sandia above Firing Range	E124	100	5	0	0	100	2	0	0					20	5	0	0	0	5	0	0	0	5	0	0	0	5	0	0
Sandia above SR-4	E125	100	2	0	0									0	2	0	0	0	2	0	0	0	2	0	0	0	2	0	0

Location ID	Windward ID	Unfiltered Aluminum				10-µm Filtered Aluminum				1-µm Filtered Aluminum				0.45-µm Filtered Aluminum				0.45-µm Filtered Copper				0.45-µm Filtered Lead				0.45-µm Filtered Zinc			
			No.				No.				No.				No.				No.				No.				No.		
		% TU>1	TU	BDL	BDL TU>1	% TU>1	TU	BDL	BDL TU>1	% TU>1	TU	BDL	BDL TU>1	% TUs>1	TU	BDL	BDL TU>1	% TUs>1	TU	BDL	BDL TU>1	% TUs>1	TU	BDL	BDL TU>1	% TUs>1	TU	BDL	BDL TU>1
Sandia below Wetlands	E123	48	42	2	0	55	11	0	0					6	48	18	0	0	48	10	0	0	48	30	0	0	48	2	0
Sandia left fork at Asph Plant	E122.LFatAP	64	11	0	0	25	4	0	0					0	11	0	0	18	11	0	0	0	11	2	0	0	11	0	0
Sandia right fork at Pwr Plant	E121	63	38	9	0	53	15	0	0					4	46	12	0	4	46	5	0	0	46	35	0	0	46	2	0
SEP-REF-BM1 at RF17BM01	SEP-REF-BM1	0	2	0	0	0	2	0	0	0	2	0	0	0	2	0	0	0	2	0	0	0	2	1	0	0	2	0	0
SEP-REF-P1 at RF17P01	SEP-REF-P1	75	4	0	0	50	4	0	0	0	4	0	0	25	4	0	0	0	4	0	0	0	4	0	0	0	4	1	0
SEP-REF-SJM1 at RF17SJM01	SEP-REF-SJM1	100	4	0	0	33	3	0	0	0	3	0	0	25	4	0	0	0	4	0	0	0	4	0	0	0	4	3	0
SEP-REF-SJM4 at RF17SJM04	SEP-REF-SJM4	100	2	0	0	0	2	0	0	0	2	0	0	0	2	0	0	0	2	0	0	0	2	2	0	0	2	1	0
South Fork of Acid Canyon	E055.5	100	1	0	0	0	3	0	0					0	7	0	0	0	7	0	0	0	7	0	0	0	7	0	0
South Fork of Sandia at E122	E122.SF	5	19	6	0									5	22	14	0	0	22	13	0	0	22	16	0	0	22	3	0
Starmers above Pajarito	E242	100	2	0	0	100	2	0	0					33	3	0	0	0	3	0	0	0	3	1	0	0	3	1	0
Ten Site above Mortandad	E201.5	100	1	0	0									100	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0
Twomile above Pajarito	E244	91	11	0	0	100	2	0	0					21	14	0	0	0	10	4	0	0	14	7	0	0	14	5	0
Water above SR-501	E252 up	83	12	0	0	100	4	0	0	0	4	0	0	42	12	0	0	**71**	7	7	**5**	0	8	8	0	0	8	5	0
Water below SR-4	E265	100	3	0	0	100	1	0	0					100	3	0	0	0	3	0	0	0	3	0	0	0	3	1	0
WR-REF-3 at RF13WR03	WR-REF-3	100	6	0	0	100	6	0	0	33	6	0	0	17	6	0	0	0	4	0	0	0	4	3	0	0	4	3	0

Bold underlined values indicate % TUs >1 is uncertain due to all TU>1 based on non-detected copper result with TU calculated using the 10-µg/L detection limit.

BDL – below detection limit
BLM – biotic ligand model
ID – identification
LANL – Los Alamos National Laboratory
TU – toxic unit
Windward – Windward Environmental LLC
WWTF – wastewater treatment plant

For the supplemental NWQMC Rio Grande dataset, Figures 4-17 and 4-18 show comparison of acute BLM- and hardness-based TUs for dissolved copper and zinc based on BLM input data for the five Rio Grande locations. Lead concentrations were not obtained, so TUs were not calculated for lead. There were no TUs > 1 for copper or zinc using BLM- or hardness-based IWQC. Figures 4-17 and 4-18 indicate that the BLM- and New Mexico hardness-based approaches consistently denote non-exceedances for both copper and zinc at the Rio Grande locations considered. Table 4-5 provides a summary of acute BLM-based TUs for each Rio Grande location identified in the NWQMC dataset.

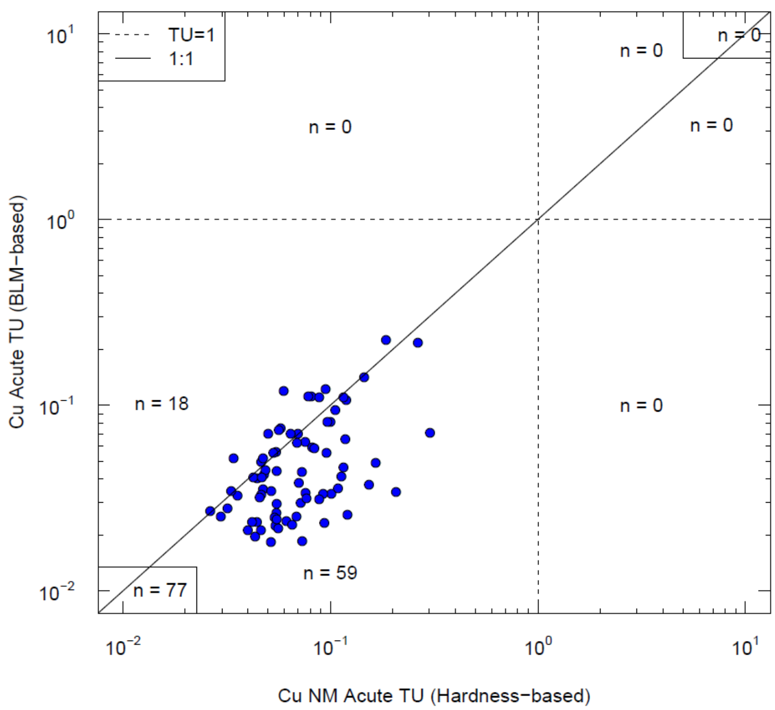


Figure 4-17. Comparison of acute dissolved copper IWQC TUs between EPA 2007 BLM and New Mexico hardness-based AWQC for the Rio Grande dataset

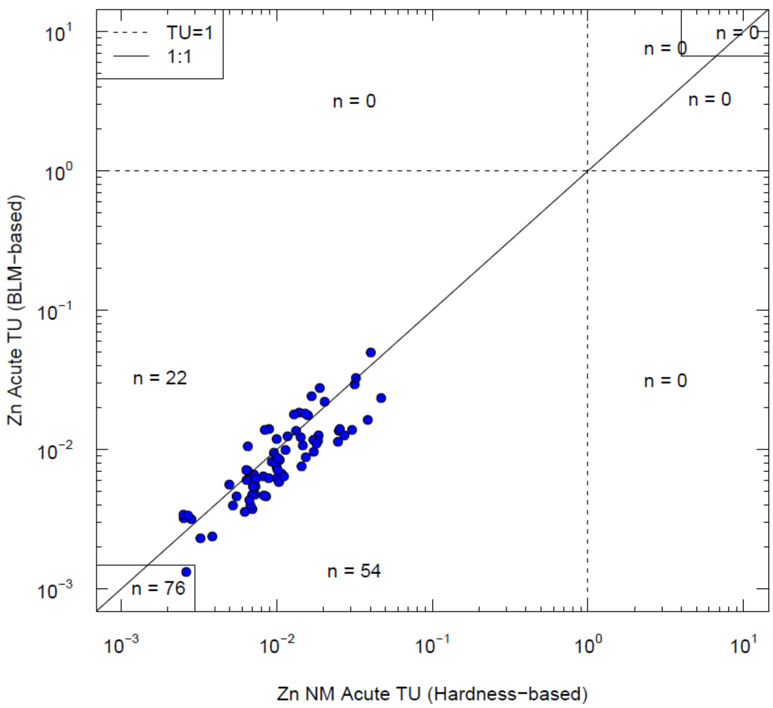


Figure 4-18. Comparison of acute <u>dissolved zinc</u> IWQC TUs between BLM and New Mexico hardness-based AWQC for the Rio Grande dataset

Table 4-5. Summary of acute BLM-based TUs for each Rio Grande location

NWQMC Location ID	Unfiltered Aluminum				0.45-µm Filtered Aluminum				0.45-µm Filtered Copper				0.45-µm Filtered Zinc			
	% TU>1	No.			% TUs>1	No.			% TUs>1	No.			% TUs>1	No.		
		TU	BDL	BDL TU>1		TU	BDL	BDL TU>1		TU	BDL	BDL TU>1		TU	BDL	BDL TU>1
Rio Grande below Taos Junction Bridge near Taos, New Mexico					0	12	6	0	0	12	7	0	0	12	10	0
Rio Grande at Otowi Bridge, New Mexico					0	13	7	0	0	13	7	0	0	13	11	0
Rio Grande below Cochiti Dam, New Mexico					0	18	0	0	0	18	9	0	0	18	16	0
Rio Grande at San Felipe, New Mexico	100	1	0	0	0	8	7	0	0	8	7	0	0	7	7	0
Rio Grande at Alameda Bridge at Alameda, New Mexico	88	26	0	0	0	26	6	0	0	26	14	0	0	26	24	0

BDL – below detection limit
BLM – biotic ligand model
ID – identification
NWQMC – National Water Quality Monitoring Council
TU – toxic unit

Also for the supplemental NWQMC dataset, Figures 4-19 and 4-20 show comparisons between acute BLM- and hardness-based IWQC TUs for unfiltered- and 0.45-µm-filtered aluminum concentrations. Similarly, Figures 4-21 and 4-22 show comparisons of EPA draft MLR- and hardness-based acute TUs for unfiltered- and 0.45-µm-filtered aluminum concentrations. Generally, the BLM generates higher TUs than the New Mexico hardness-based IWQC, indicating that for the Rio Grande dataset, the BLM generates lower IWQC. The MLR-based TUs are often higher than the hardness-based TUs, although the MLR-based TUs are more similar to the hardness-based TUs than are the BLM-based TUs. As described above, interpreting the patterns for aluminum is complicated and subjective given the uncertainty in appropriate sample preparation, criteria basis, and contribution from natural background.

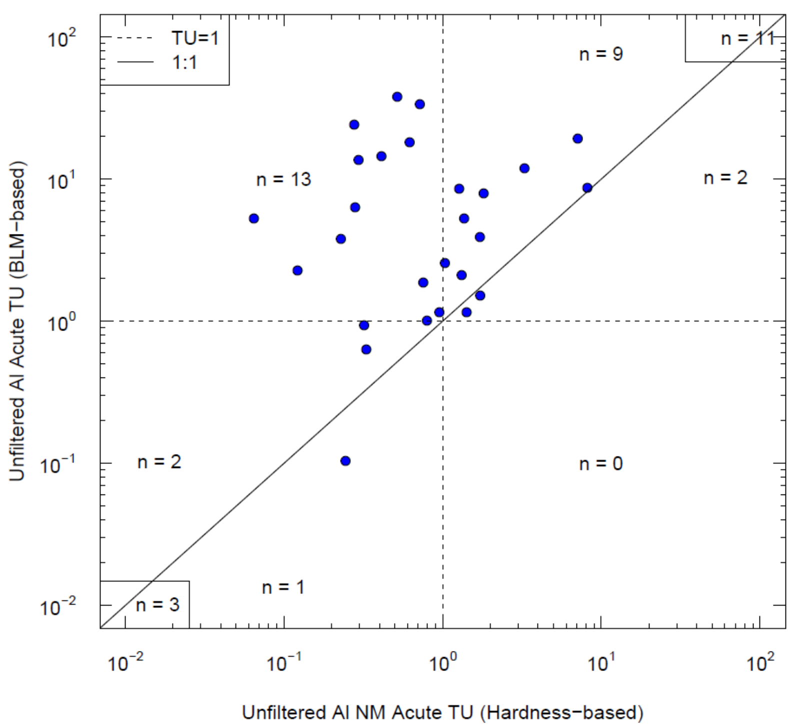


Figure 4-19. Comparison of acute aluminum IWQC TUs between BLM and New Mexico hardness-based AWQC (on basis of unfiltered aluminum) for the Rio Grande dataset

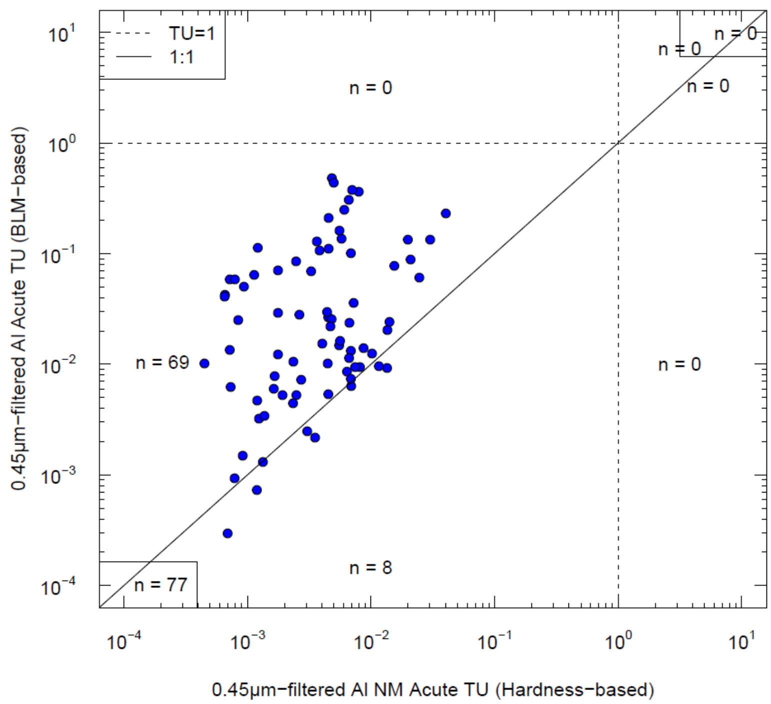


Figure 4-20. Comparison of acute <u>aluminum</u> IWQC TUs between BLM and New Mexico hardness-based AWQC (on basis of <u>0.45 µm filtered</u> aluminum) for the Rio Grande dataset

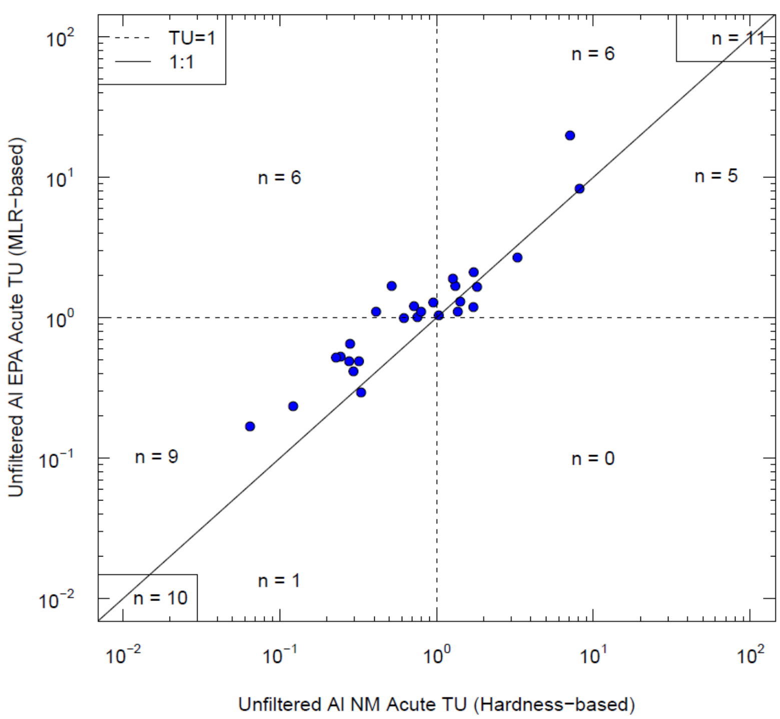


Figure 4-21. Comparison of EPA draft <u>MLR-based</u> acute TUs and New Mexico hardness-based TUs for aluminum (for <u>unfiltered</u> aluminum) for the Rio Grande dataset

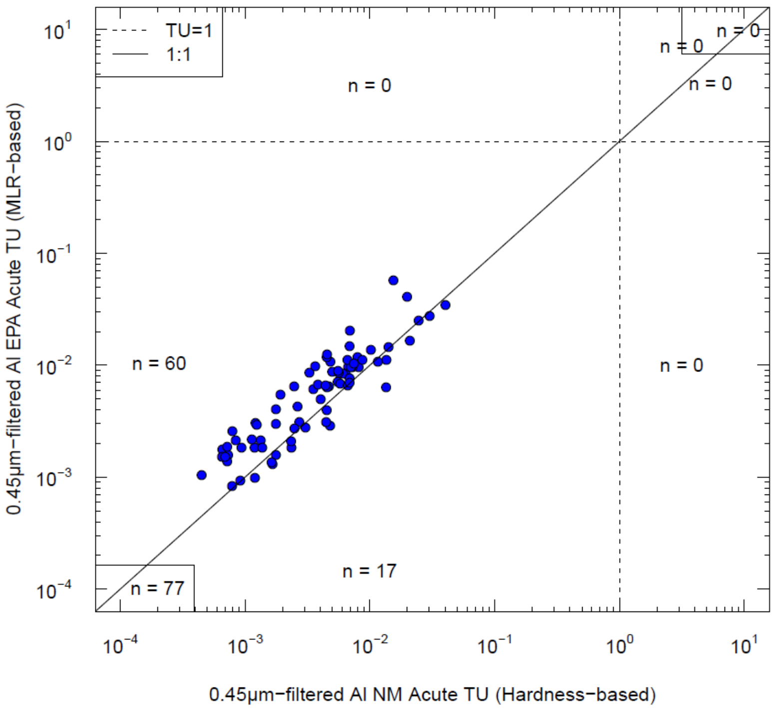


Figure 4-22. Comparison of EPA draft <u>MLR-based</u> acute TUs and New Mexico hardness-based TUs for aluminum (for <u>0.45-µm filtered</u> aluminum) for the Rio Grande dataset

4.4 SPATIAL PATTERNS IN ACUTE IWQC

Figure 4-23 provides a longitudinal summary of acute BLM-based copper TU results for the Los Alamos watershed (mainstem and two tributaries). This type of data visualization can help illustrate the spatial distributions of the large differences between the acute TUs for BLM-based and hardness based IWQC. In Figure 4-23. One can see that all three DP canyon locations exhibit similar results, illustrating the significant false positive concern for hardness-based copper IWQC pointed out in Section 4.3. Similar longitudinal series of boxplots for the minor watersheds are provided in Appendix A.

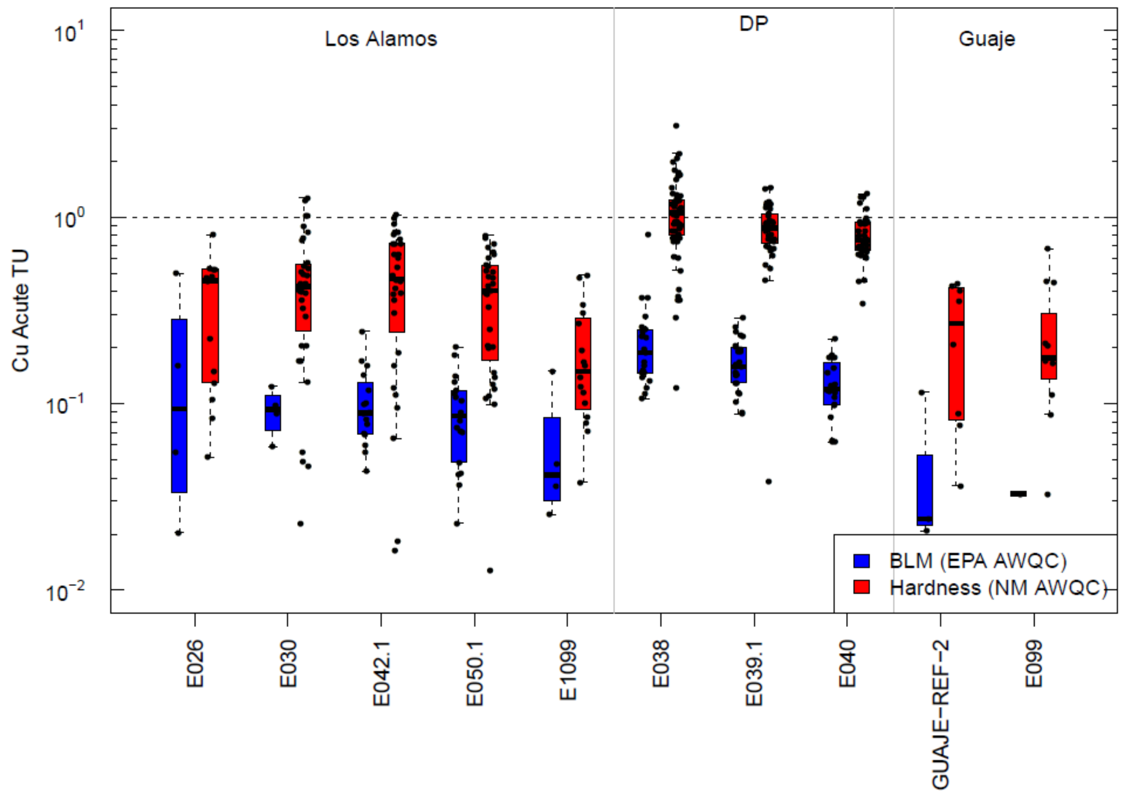


Figure 4-23. Los Alamos Watershed longitudinal summary of acute dissolved copper IWQC TUs based on BLM and New Mexico (NM) IWQC

For copper, BLM-based IWQC exceedances (TUs > 1, n=11) were limited to 5 locations:E056, E243, E122.LFatAP (Sandia Left fork at Asph plant), E121 and E252 (Water canyon above SR-501). It is important to note that 7 of the IWQC exceedances were attributable to BDL copper results where the copper detection limits were 10 µg/L, which exceeded the respective BLM-based IWQC. These occurrences were most pronounced at E252 and should be regarded as artifactual results and not relied up given the copper DL was approximately 3-fold higher than typical DLs reported in the dataset (~ 3 µg/L). The four remaining IWQC exceedances were limited to two locations in Upper Sandia canyon (E121 and E122.LFatAP).

Another potential concern for the acute copper BLM IWQC results is apparent in the Sandia Canyon watershed for E122.LFatAP. See Figure 4-24. This location had only WT (storm water) sample types which were associated with lower BLM-based IWQC (n=11) than the 22 baseflow (WS or WP) sample events at this same gage station coordinates (E122) but that were identified by EIM with different nomenclature (South Fork of Sandia at E122, i.e. E122.SF Windward ID). The stormflow E122 (WT) events had lower average pH (7.0) than the average pH of 8.5 in the E122 baseflow (WS, WP) events, while DOC was similar across all events at E122 (average 12 mg/L for WT, and 12.2 mg/L for WS, WP events).

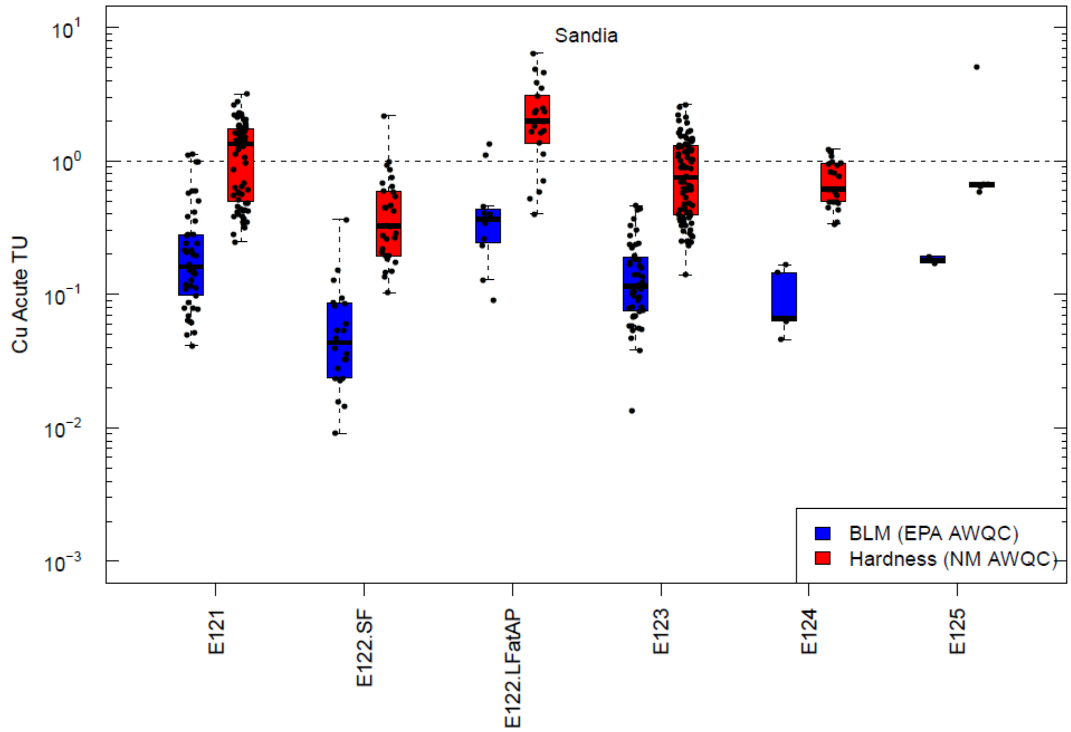


Figure 4-24. Sandia Canyon longitudinal summary of acute dissolved copper IWQC TUs based on BLM and New Mexico (NM) IWQC

Given the BLM sensitivity to pH it is apparent that the lower pH of the stormflow samples at E122 is a significant consideration, which is not surprising given the runoff from the significant impervious surface area in the associated watershed (rainfall is naturally acidic with pH~5.5). Considering spatial patterns in the Upper Sandia perennial waters, not far downstream from E122, BLM events from gage station E123 (Sandia below wetland) exhibited no BLM-based IWQC TUs>1 across a large dataset (n=49 BLM events) nearly evenly distributed between stormflow (n=22) and baseflow (n=27). See Figure 4-24, which again helps to illustrate the significant false positive rate of the hardness-based copper IWQC. Additional longitudinal summaries based on chronic IWQCs are provided in Appendix B.

A longitudinal summary of BLM- and hardness-based acute copper TUs for the supplemental NWQMC dataset for the Rio Grande is shown in Figure 4-25. While BLM-based acute copper TUs are generally lower than hardness-based TUs, the TUs for the Rio Grande are generally lower than those calculated for the LANL dataset. This pattern is likely due to differences in copper concentrations and/or water chemistry (e.g., DOC, pH, and hardness) between the Rio Grande perennial waters and the ephemeral/intermittent surface waters of the Pajarito Plateau. Additional longitudinal summaries based on both acute and chronic IWQCs are provided for the Rio Grande in Appendix C.

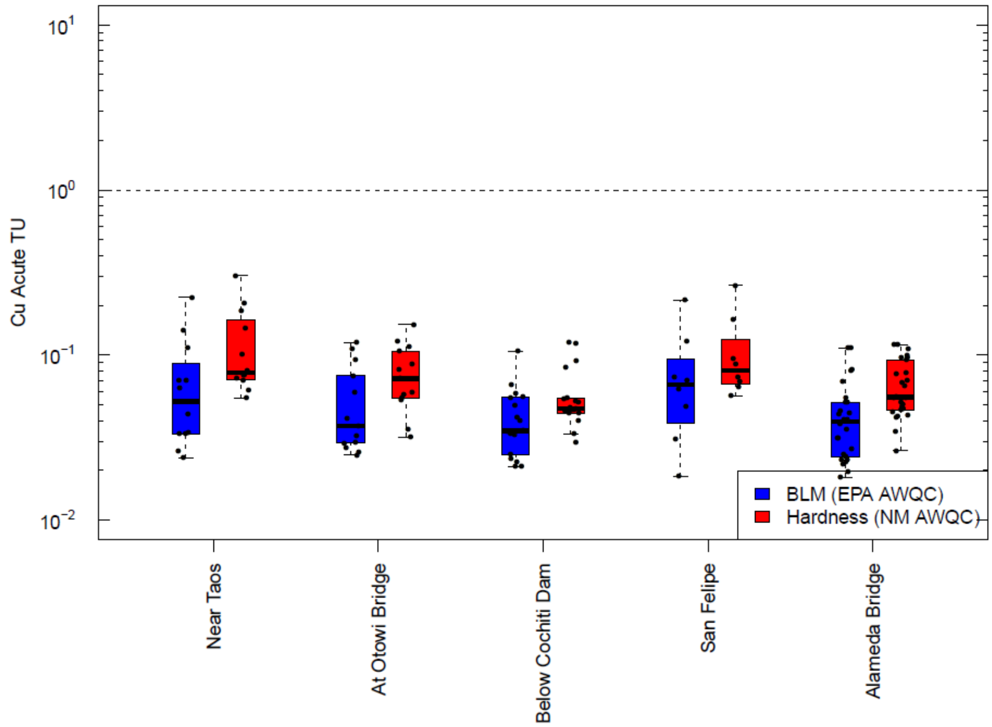


Figure 4-25. Longitudinal summary of acute dissolved copper IWQC TUs based on BLM and New Mexico (NM) IWQC from the Rio Grande dataset

4.5 Evaluation of Time-Variable Acute IWQC for FMBs and Other Potential SSWQC Outcomes

Location-specific acute BLM-based FMBs were calculated for each metal for locations containing at least 10 BLM-based TUs. A summary of acute FMBs for copper, lead, and zinc by sampling location is provided in Table 4-6; FMBs for minor watersheds are described in Section 4.6. Figure 4-26 provides a graphical representation of the BLM-based copper FMB derived for E042.1 as an example. In this figure, "AFa" is the acute adjustment factor applied to the distribution of copper TUs (green dashed line) such that the projected IWQC exceedance frequency is equal to once in three years (the 99.9th percentile). In this case, the AF is 2.56, which is applied to shift the dissolved copper distribution (red dashed line) upwards so that it intersects a value of 15.06 µg/L, which is the FMB. Appendix D provides comprehensive plots of acute IWQC and TUs over time and the corresponding plots used to derive the FMBs for each metal for each location and by minor watershed groups of locations. Plots are also included for aluminum FMBs based on the various filter size sample preparations.

Table 4-6. Acute BLM-based FMB results for copper, lead, and zinc by location

Location ID	Windward ID	Copper (µg/L)	Lead (µg/L)	Zinc (µg/L)
Acid above Pueblo	E056	5.7	175	294
Canon de Valle below MDA P	E256			218
DP above Los Alamos Canyon	E040	12.2	270	356
DP above TA-21	E038	14.2	275	338
DP below grade ctrl structure	E039.1	19.6	177	368
Los Alamos above low-head weir	E042.1	15.1	161	253
Los Alamos below low-head weir	E050.1	14.1	275	305
Mortandad below Effluent Canon	E200	11.5	263	415
Pajarito above Threemile	E245.5	11.2	217	497
Pajarito above Twomile	E243		237	306
Pueblo above Acid	E055	9.6	155	308
Sandia below Wetlands	E123	11.3	276	341
Sandia left fork at Asph Plant	E122.LFatAP	35.3	101	2100
Sandia right fork at Pwr Plant	E121	4.8	58	218
South Fork of Sandia at E122	E122.SF	84.8	1110	787
Twomile above Pajarito	E244	5.1	252	195
Water above SR-501	E252 up			

Note: 1) results shown for locations with more than 10 available TUs, 2) FMBs are based on 0.45µm filtered ("dissolved") metal concentrations and BLM-based IWQCs which are also on a dissolved basis.

BLM – biotic ligand model
FMB – fixed monitoring benchmark
ID – identification
IWQC – instantaneous water quality criteria
TU – toxic unit
Windward – Windward Environmental LLC

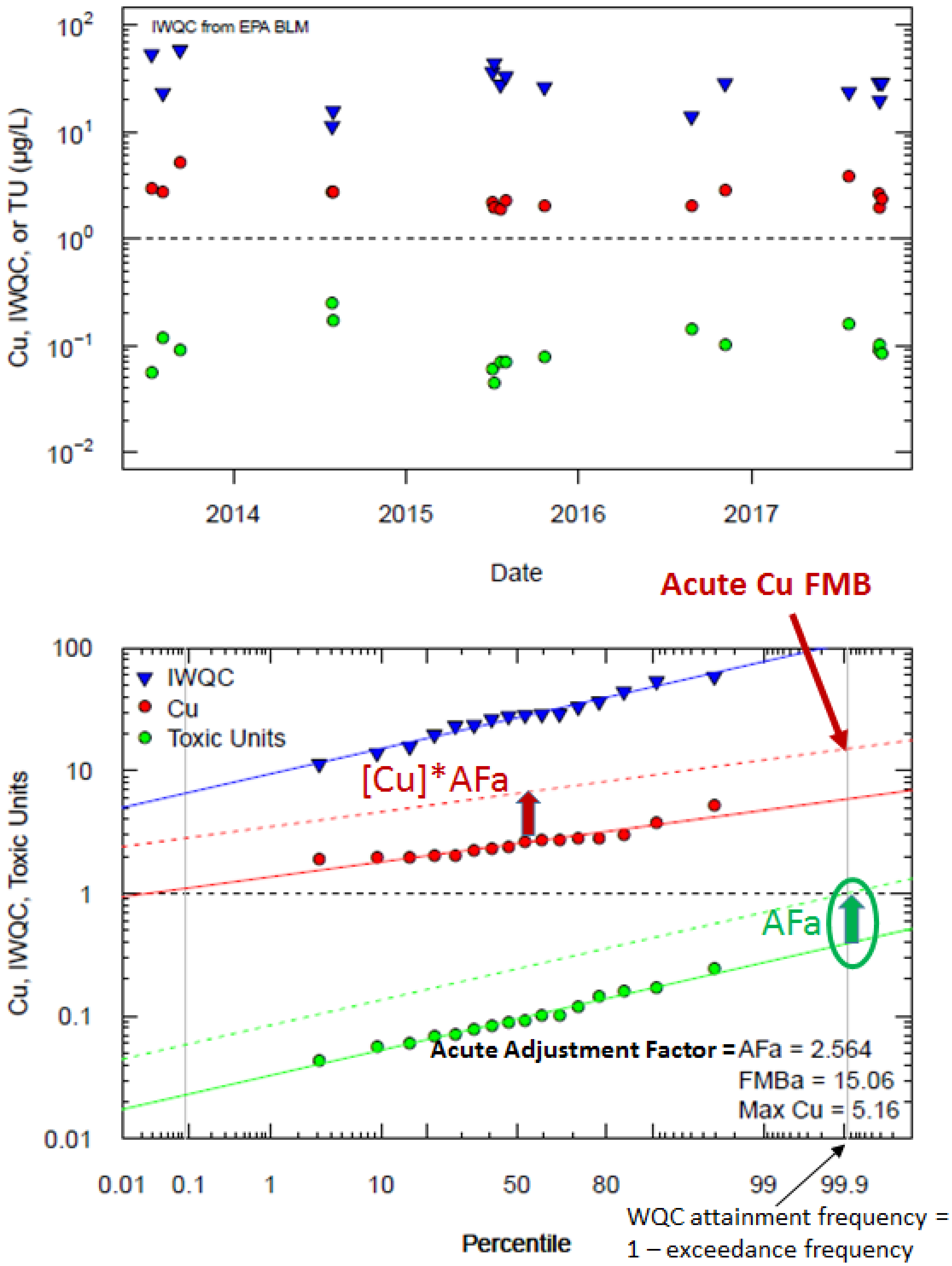


Figure 4-26. Example BLM-based acute copper FMB for E042.1

Table 4-7 provides a summary of acute BLM- and MLR-based FMB results for aluminum by location, and Table 4-8 provides a summary of acute BLM- and MLR-based FMB results for aluminum by minor watershed. The resulting FMBs vary considerably between the six permutations possible (three filter preparations x two AWQC basis). Care must be taken in interpreting the aluminum FMBs given the uncertainty in 1) the EPA MLR-based AWQC are draft subject to finalization, 2) the BLM has broader bounds than the MLR-based AWQC for DOC and pH as indicated in EPA 2017 and associated literature, 3) the criteria implementation basis (UF, vs F10 vs F0.45), and the significance of impacts from aluminum in the natural background conditions(LANL 2017b, 2016, 2015, 2014, 2013, 2010a, b, 2007).

Table 4-7. Acute aluminum BLM- and MLR-based FMB results based on filter size preparation by location

Location ID	Windward ID	BLM (µg/L)			MLR (µg/L)		
		UF	F10	F0.45	UF	F10	F0.45
Acid above Pueblo	E056	1307		998	1493		1550
Canon de Valle below MDA P	E256	659		503	4204		4988
DP above Los Alamos Canyon	E040	862	991	832	4699	4282	3893
DP above TA-21	E038	695	714	1002	2355	3373	2850
DP below grade ctrl structure	E039.1	1314	636	819	2911	4634	2818
Los Alamos above low-head weir	E042.1	1027		622	2091		2317
Los Alamos below low-head weir	E050.1	2405		1194	2300		2019
Mortandad below Effluent Canon	E200	1398		1384	3588		3564
Pajarito above Threemile	E245.5	2041		1337	830		944
Pajarito above Twomile	E243	1525		1009	3042		2294
Pueblo above Acid	E055	1531		861	1735		1931
Sandia below Wetlands	E123	1339	648	972	2273	3020	2063
Sandia left fork at Asph Plant	E122.LFatAP	339		172	2020		1694
Sandia right fork at Pwr Plant	E121	572	210	689	1770	2602	1467
South Fork of Sandia at E122	E122.SF	1216		611	2972		3360
Twomile above Pajarito	E244	3130		1015	914		1630
Water above SR-501	E252 up	2426		775	3380		883

Note: Results based on 10 or more IWQC and TU results.

BLM – biotic ligand model
F – filtered
FMB – fixed monitoring benchmark
ID – identification
IWQC – instantaneous water quality criteria
MLR – multiple linear regression
TU – toxic unit
UF – unfiltered
Windward – Windward Environmental LLC

Table 4-8. Acute aluminum BLM- and MLR-based FMB results based on filter size preparation by minor watershed

Canyon	2015 Draft IP MTAL (µg/L)	BLM (µg/L)			MLR (µg/L)		
		UF	F10	F0.45	UF	F10	F0.45
Acid	442	1360		1064	1461		1625
Canon de Valle	974	659		503	4204		4988
DP	688	899	913	970	3040	4651	3489
Los Alamos	1042	3038	783	837	3727	3866	2234
Mortandad	554	2029		1283	3215		2718
Pajarito	1069	3305	1579	1266	1354	3517	1738
Pueblo	985	1058		907	1673		1721
Sandia	1490	1377	299	901	2310	3397	1784
Twomile	628	3130		1015	914		1630
Water	965	737		430	4281		1408

Note: Blank cells indicate that there were no data, or insufficient data for calculating FMBs
Results based on 10 or more IWQC and TU results.

BLM – biotic ligand model
F – filtered
FMB – fixed monitoring benchmark
IWQC – instantaneous water quality criteria
MLR – multiple linear regression
MTAL – maximum target action level
UF – unfiltered
TU – toxic unit

Additionally, 10th, 25th and 50th percentiles of acute BLM-based IWQCs for copper, lead, and zinc are provided for the LANL dataset in Table 4-9 (for locations with at least 10 calculated TUs). Table 4-10 provides a similar summary of acute BLM- and MLR-based IWQC percentiles for aluminum by location for the LANL dataset, and Table 4-11 provides a summary of IWQC percentiles calculated for the Rio Grande dataset.

Where data are absent or insufficient to generate BLM-based IWQC for a location of interest, using conservative percentile IWQC results from other, representative locations that have BLM-based IWQC datasets may be a useful initial approach for screening observed metals concentrations. For example, the State of Idaho's guidance recommends NPDES permit writers use the minimum 10th percentile of BLM-based IWQC for 189 locations characterized in 2016 as part of that state's initial BLM rulemaking effort (IDEQ 2017).

Additionally, as an alternative for reconciling time-variable IWQC when data are insufficient for calculating FMBs, conservative percentiles have been proposed for initial screening purposes (McConaghie and Matzke 2016). EPA has gone so far as to indicate that the 2.5th percentile IWQC may need to be used for conservatism (EPA 2016), although caution must be exercised when using such an approach to evaluate any unintended over-conservatism. The 10th, 25th, and 50th BLM-based IWQC percentiles were also evaluated by Oregon DEQ in its 2016 Technical Support Document used for statewide copper criteria evaluations using the BLM (McConaghie and Matzke 2016). Lastly, the 50th percentile (median) is provided as a general measure of central tendency that can be compared with the hardness-based IP MTALs that have been based on geometric mean or average hardness.

Careful consideration of the key differences between FMBs and IWQC are needed while interpreting the time-variable outcomes provided herein. Significant differences in BLM IWQC and TU results among multiple locations may affect FMBs derived for multiple locations within a particular canyon or AU grouping. Similarly, certain locations may contain BLM events dominated by certain sample types, e.g., WT – stormflow versus WM/WP/WS baseflow that may have experienced significantly different water quality that might lead to correspondingly different IWQC and/or FMBs.

Specifically, the copper BLM-based FMBs for the four sampling locations in the Upper Sandia AU varied across an order of magnitude between 4.8 and 85 µg/L (see Table 4-6, copper FMBs, for locations "Sandia right fork at Pwr Plant (E121)" and "South Fork of Sandia at E122 (E122.SF)"). Meanwhile, an overall copper FMB of 8.5 µg/L for all four locations in the AU grouped together (Table 4-12) was approximately an order of magnitude lower than the highest individual Sandia location FMB. Interestingly, among the four locations (n=127 BLM datasets), copper would exceed an FMB in 16 samples, while 6 of those results would not have exceeded BLM-based acute IWQC. In practice, exceedances of an IWQC (or lack thereof) should take precedence over exceedances of an FMB for a particular sample result. Some of this contrast may reflect significant differences between baseflow and stormflow water quality that will require further consideration, especially where pH measurements are concerned as described in Section 4.4. This situation is applicable to lead and zinc BLM-based FMBs for Sandia as well, which is not surprising because those metal BLMs behave similarly to the copper BLM.

Table 4-9. Acute copper, lead and zinc BLM IWQC percentiles by location

Location ID	Windward ID	Median Hardness (mg/L as calcium carbonate)	Copper (µg/L)			Lead (µg/L)			Zinc (µg/L)		
			10th Percentile	25th Percentile	50th Percentile	10th Percentile	25th Percentile	50th Percentile	10th Percentile	25th Percentile	50th Percentile
Acid above Pueblo	E056	20	7.4	8.9	16	160	180	210	240	250	290
Canon de Valle below MDA P	E256	66	10	12	18	130	160	180	190	210	250
DP above Los Alamos Canyon	E040	28	16	20	26	220	260	330	230	270	300
DP above TA-21	E038	28	8.1	11	13	120	150	210	160	180	220
DP below grade ctrl structure	E039.1	25	12	16	20	160	200	280	200	220	290
Los Alamos above low-head weir	E042.1	34	15	22	28	260	280	310	270	290	330
Los Alamos below low-head weir	E050.1	45	17	23	33	290	340	370	280	310	350
Mortandad below Effluent Canon	E200	28	16	23	26	240	270	350	310	350	360
Pajarito above Threemile	E245.5	24	8.3	16	25	170	230	310	280	320	370
Pajarito above Twomile	E243	35	10	20	24	160	210	250	210	230	270
Pueblo above Acid	E055	39	23	28	32	310	340	380	320	320	360

Location ID	Windward ID	Median Hardness (mg/L as calcium carbonate)	Copper (µg/L)			Lead (µg/L)			Zinc (µg/L)		
			10th Percentile	25th Percentile	50th Percentile	10th Percentile	25th Percentile	50th Percentile	10th Percentile	25th Percentile	50th Percentile
Sandia below Wetlands	E123	53	17	28	40	240	290	370	240	270	340
Sandia left fork at Asph Plant	E122.LFatAP	26	7.1	16	22	97	200	230	210	240	300
Sandia right fork at Pwr Plant	E121	27	9.3	14	31	130	190	250	160	210	240
South Fork of Sandia at E122	E122.SF	111	79	100	120	490	570	710	320	380	480
Twomile above Pajarito	E244	30	8.9	14	21	180	210	240	220	230	300
Water above SR-501	E252 up	46	2.1	4.2	6.5	39	78	120	160	170	200

Note: Results based on 10 or more IWQC and TU results.

BLM – biotic ligand model
ID – identification
IWQC – instantaneous water quality criteria
Windward – Windward Environmental LLC

Table 4-10. Acute total aluminum IWQC percentiles based on BLM and MLR by location

Location ID	Windward ID	Median Hardness (mg/L calcium carbonate)	Aluminum BLM (µg/L)			Aluminum MLR (µg/L)		
			10th Percentile	25th Percentile	50th Percentile	10th Percentile	25th Percentile	50th Percentile
Acid above Pueblo	E056	20	720	820	1100	1600	1900	2200
Canon de Valle below MDA P	E256	66	610	720	840	2800	3400	3600
DP above Los Alamos Canyon	E040	28	790	900	1000	3100	3600	3600
DP above TA-21	E038	28	570	640	880	1900	2200	2600
DP below grade ctrl structure	E039.1	25	720	810	1100	2600	2800	3100
Los Alamos above low-head weir	E042.1	34	850	1100	1200	2300	2700	3500
Los Alamos below low-head weir	E050.1	45	820	980	1400	2600	3200	3800
Mortandad below Effluent Canon	E200	28	970	1100	1300	2800	3100	3900
Pajarito above Threemile	E245.5	24	990	1200	1800	1200	1500	2100
Pajarito above Twomile	E243	35	690	800	1100	3000	3400	3900
Pueblo above Acid	E055	39	1100	1100	1200	2300	3500	3800
Sandia below Wetlands	E123	53	620	790	920	2500	3300	3800
Sandia left fork at Asph Plant	E122.LFatAP	26	640	900	1100	1400	2200	2400
Sandia right fork at Pwr Plant	E121	27	380	480	660	2200	2500	3200
South Fork of Sandia at E122	E122.SF	111	470	660	820	1700	2400	3100
Twomile above Pajarito	E244	30	590	670	1000	1600	1900	2900
Water above SR-501	E252 up	46	400	450	640	1300	1800	2500

Note: Results based on 10 or more IWQC and TU results.

BLM – biotic ligand model
ID – identification
IWQC – instantaneous water quality criteria
MLR – multiple linear regression
Windward – Windward Environmental LLC

Table 4-11. Acute copper, lead, and zinc BLM IWQC percentiles and acute aluminum BLM and MLR IWQC percentiles for the Rio Grande dataset

Location ID	Date Range	No. of Events	Median Hardness (mg/L)	Copper (µg/L)			Lead (µg/L)			Zinc (µg/L)			Aluminum BLM (µg/L)			Aluminum MLR (µg/L)		
				10th Percentile	25th Percentile	50th Percentile	10th Percentile	25th Percentile	50th Percentile	10th Percentile	25th Percentile	50th Percentile	10th Percentile	25th Percentile	50th Percentile	10th Percentile	25th Percentile	50th Percentile
Rio Grande below Taos Junction Bridge near Taos, New Mexico	2005 to 2010	12	97	12	13	26	86	104	163	93	111	159	58	214	930	1300	1300	1550
Rio Grande at Otowi Bridge, New Mexico	2005 to 2010	13	109	11	17	22	104	142	211	125	158	239	91	160	499	1400	1900	2600
Rio Grande below Cochiti Dam, New Mexico	2009 to 2015	18	120	15	17	23	163	192	223	216	231	264	120	227	826	2800	3125	3600
Rio Grande at San Felipe, New Mexico	2005 to 2008	8	114	12	15	20	122	135	175	147	149	198	66	70	374	1770	1875	2150
Rio Grande at Alameda Bridge at Alameda, New Mexico	2005 to 2015	27	122	15	20	30	173	196	254	196	227	255	84	195	1308	2000	2550	3200

BLM – biotic ligand model
ID – identification
MLR – multiple linear regression
IWQC – instantaneous water quality criteria

In contrast, most other FMBs were relatively similar between the individual locations (Table 4-6) and the pooled locations among the various canyons (Table 4-12). For example, the range of copper FMBs for individual and pooled locations for DP, Los Alamos, Mortandad and Pajarito canyons fell within a relatively narrow range of 11 to 15 µg/L, and none of the observed copper concentrations exceeded any FMB basis. The dataset for these four canyons contains nearly 200 BLM sample events across most of the past 13 years, with over 130 samples collected in the past 5 years, thus is robust and sound for considering BLM-based alternative AWQC (as IWQCs or FMBs).

4.6 POTENTIAL TARGET ACTION LEVELS FOR THE LANL INDIVIDUAL PERMIT

This section provides a summary of how some of the above-described outcomes might be used for NPDES permit compliance. In the case of LANL's NPDES individual permit (IP) for solid waste management units and areas of concern, acute hardness-based New Mexico AWQC are used as the current basis for maximum target action levels (MTALs). The MTALs are used to determine compliance activities based on storm water sampling results. In the 2010 IP, the metals MTALs were based on a 30-mg/L hardness[14], which yielded one-size-fits-all MTALs for dissolved copper, lead, and zinc of 4.3, 17, and 42 µg/L, respectively (while in effect in early 2010, MTALs based on hardness-based New Mexico AWQC for aluminum were not included in the 2010 IP by EPA). In contrast, the 2015 draft IP, in its Appendix F proposed ranges of MTALs for these metals, including aluminum across the numerous canyon watersheds; the MTALs were based on acute New Mexico AWQC using spatially aggregated average hardness results for surface water samples for each canyon.

The 2015 draft IP MTALs for copper, lead, and zinc are provided in Table 4-12, which also contains BLM-based acute FMBs for canyons for which 10 or more BLM acute IWQC and TU datasets were available, as identified in Section 4.2. Table 4-12 also provides median BLM acute IWQC for copper, lead and zinc for canyons with 10 or more BLM events. This table provides columns for each metal showing the factor difference between the acute BLM-based potential MTALs and the 2015 draft IP MTALs. The table also provides median hardness results for each canyon derived from the BLM dataset aggregated herein (10 or more samples).

In either case of the BLM application (acute FMBs or median acute IWQC), the differences with respect to the 2015 draft IP MTALs were most pronounced for lead (14- to 18-fold higher on average) and zinc (5-fold higher on average). All BLM-based acute copper FMBs were higher than the 2015 draft IP MTALs, ranging from 10% higher for Sandia to 6.2 times higher for Water canyon. Meanwhile, acute BLM IWQC ranged from 3.2 to 7.8 times higher than the 2015 MTALs. Thus, using either BLM-

[14] A 2008 LANL report indicates an overall geometric mean hardness of 30.1 mg/L and a median of 29.2 mg/L for filtered hardness results from 423 samples collected in receiving waters across LANL watersheds(LANL 2008).

based MTAL (acute FMB or median acute IWQC) for any of these three metals would likely yield different compliance scenarios. If it is accepted that the BLM provides more accurate environmental protection than do hardness-based AWQC, especially given the level of vetting behind the EPA 2007 copper BLM-based AWQC, it follows that BLM-based MTALs also can lead to more accurate decision making for storm water compliance needs while maintaining the level of environmental protection intended by EPA.

For aluminum, the potential new MTALs are a more complex set of outcomes related to the different combinations of sample preparations (e.g., UF, F0.45, F10 and F1) and the three types of AWQC evaluated (i.e., BLM, EPA 2017 MLR, and New Mexico 2010). Tables 4-7 and 4-13 provide the summaries accordingly.

Table 4-12. Potential BLM-based IP MTALs for copper, lead, and zinc by canyon

Canyon	2015 Draft IP Hardness	Median Hardness (mg/L)	Change in Hardness (%)	Dissolved Copper (µg/L) 2015 Draft IP MTAL	BLM FMB[a]	Factor Diff. from IP	BLM IWQC Median	Factor Diff. from IP	Acute New Mexico WQC[b]	Dissolved Lead (µg/L) 2015 Draft IP MTAL	BLM FMB[a]	Factor Diff. from IP	BLM IWQC Median	Factor Diff. from IP	Acute New Mexico WQC[b]	Dissolved Zinc (µg/L) 2015 Draft IP MTAL	BLM FMB[a]	Factor Diff. from IP	BLM IWQC Median	Factor Diff. from IP	Acute New Mexico WQC[b]
Acid	22	20	-13%	3.3	9.1	2.8	17	5.2	3.0	12	223	18	210	17	10	41	346	8.4	310	7.5	37
South Fork Acid	21			3.1						12						39					
Ancho	40	43	7%	5.6					6.3	23					27	69					75
North Fork Ancho	30			4.3						17						54					
Arroyo de la Delfe	22			3.2						12						40					
Bayo	59			8.1						36						99					
Canada del Buey	39			5.5						23						67					
Canon de Valle	40	66	66%	5.7			18	3.2	9.5	23			180	7.7	48	69	218	3.1	250	3.6	113
Chaquehui	30	25	-18%	4.3					3.7	17					14	54					46
DP	31	26	-15%	4.5	14.5	3.3	19	4.3	4.0	18	230	13	250	14	15	55	339	6.2	280	5.1	49
Fence	68			9.4						42						113					
Graduation	31			4.5						18						55					
Los Alamos	42	47	11%	5.9	13.7	2.3	29	4.9	6.8	25	219	8.8	370	15	31	73	221	3.0	350	4.8	82
Mortandad	26	30	12%	3.8	12.7	3.3	30	7.8	4.5	15	290	19	400	27	17	48	325	6.8	410	8.6	54
Pajarito	43	32	-24%	6.0	14.8	2.5	24	4.0	4.8	25	237	9.3	290	11	19	74	395	5.3	360	4.9	59
Potrillo	21			3.1						12						39					
Pratt	26			3.8						15						48					
Pueblo	40	39	-4%	5.7	9.7	1.7	35	6.1	5.7	24	173	7.3	410	17	24	70	423	6.0	370	5.3	69
Rendija	115			15.3						75						181					
Sandia	55	48	-12%	7.6	8.5	1.1	40	5.3	7.0	33	172	5.2	350	11	32	92	282	3.1	320	3.5	84
Ten-Site	16			2.4						8.3						30					
Threemile	29			4.2						17						52					
Twomile	29	30	4%	4.2	5.1	1.2	21	5.0	4.5	16	252	15	240	15	18	52	195	3.8	300	5.8	55
Walnut	23			3.3						13						42					
Water	40	43	8%	5.6	35.1	6.2	19	3.4	6.3	23	1479	63	260	11	28	69	303	4.4	230	3.3	76

Note: Median based on 10 or more results unless indicated by *.
Blank cells indicate that there were no data or insufficient data for calculating FMBs.
[a] FMBs shown only for locations with 10 or more IWQC and TU results.
[b] New Mexico WQC are based on median hardness.

BLM – biotic ligand model
FMB – fixed monitoring benchmark
IP – individual permit
IWCQ – instantaneous water quality criteria
MTAL – maximum target action level
WQC – water quality criteria

Table 4-13. Potential BLM- and MLR-based IP MTALs for total aluminum by canyon

Canyon	2015 Draft IP		Median Hardness (mg/L)	Total Aluminum (µg/L)				
				Acute FMB[a,b]		Acute IWQC Median Values[c]		
	Hardness	MTAL (µg/L)		BLM	EPA 2017 MLR	BLM	EPA 2017 MLR	New Mexico 2010
Acid	22	442	20	1360	1461	1200	2200	365
South Fork Acid	21	414						
Ancho	40	966	43					1060
North Fork Ancho	30	658						
Arroyo de la Delfe	22	427						
Bayo	59	1649						
Canada del Buey	39	926						
Canon de Valle	40	974	66	659	4204	840	3600	1948
Chaquehui	30	667	25					501
DP	31	688	26	899	3040	1000	3200	549
Fence	68	2026						
Graduation	31	692						
Los Alamos	42	1042	47	3038	3727	1400	4000	1200
Mortandad	26	554	30	2029	3215	1300	4200	650
Pajarito	43	1069	32	3305	1354	1400	3000	731
Potrillo	21	409						
Pratt	26	554						
Pueblo	40	985	39	1058	1673	1300	3900	935
Rendija	115	4122						
Sandia	55	1490	48	1377	2310	890	3300	1250
Ten-Site	16	274						
Threemile	29	639						
Twomile	29	628	30	3130	914	1000	2900	664
Walnut	23	452						
Water	40	965	43	737	4281	600	2500	1072

Note: Blank cells indicate that there were no data or insufficient data for calculating FMBs.

[a] FMBs shown only for locations with 10 or more available IWQC and TU results.

[b] FMBs based on TUs for unfiltered aluminum.

[c] Median IWQC based on 10 or more results.

BLM – biotic ligand model
EPA – US Environmental Protection Agency
FMB – fixed monitoring benchmark
IP – individual permit
IWQC – instantaneous water quality criteria
MLR – multiple linear regression
MTAL – maximum target action level
TU – toxic unit

4.7 APPLICATION OF BLM CHRONIC IWQC TO PERENNIAL SURFACE WATERS

Chronic IWQC were generated for all sample events, but only evaluated for specific LANL waters currently designated in §126 NMAC as perennial waters (e.g., upper Sandia, and specific AUs in Water Canyon and Canon de Valle). Although chronic IWQC are technically applicable to §98 NMAC waters (i.e., default intermittent) such as the greater Pueblo Canyon, chronic IWQC were not evaluated for these waters, partly to avoid potential confusion, since it is understood that some of these waters are being (or will be) evaluated under the NMED Hydrology Protocol use attainability analysis approach to determine whether habitat and hydrology support an aquatic life use that may or may not be subject to chronic AWQC.

Figures 4-27 to 4-29 portray comparisons of chronic IWQC TUs for §126 NMAC perennial waters in the LANL dataset. Similar patterns emerge consistent with those for the acute IWQC comparisons in Section 4.2, although the false positive rates for chronic IWQC based on hardness are now significant for lead (49%) and zinc (12%). For copper, the hardness-based chronic IWQC exhibited resulted in false positives over the BLM-based chronic IWQC in nearly half the samples (49%). Chronic aluminum IWQC TU plots for the LANL dataset are provided in Appendix E, and chronic copper, zinc, and aluminum IWQC TU plots for the Rio Grande dataset are also provided in Appendix F.

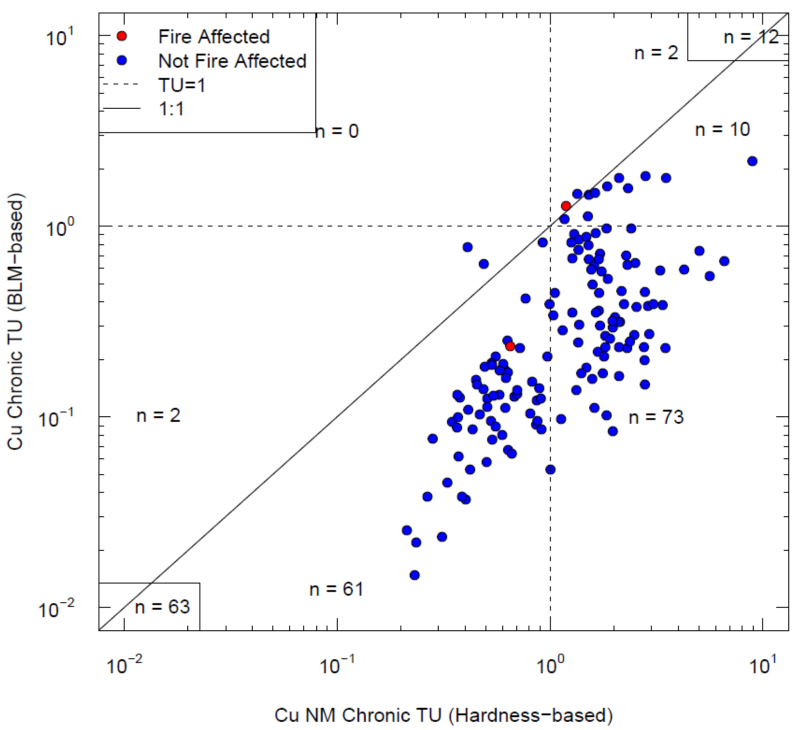


Figure 4-27. Comparison of dissolved <u>copper chronic IWQC</u> TUs based on BLM and New Mexico AWQC for NMAC Class 126 waters

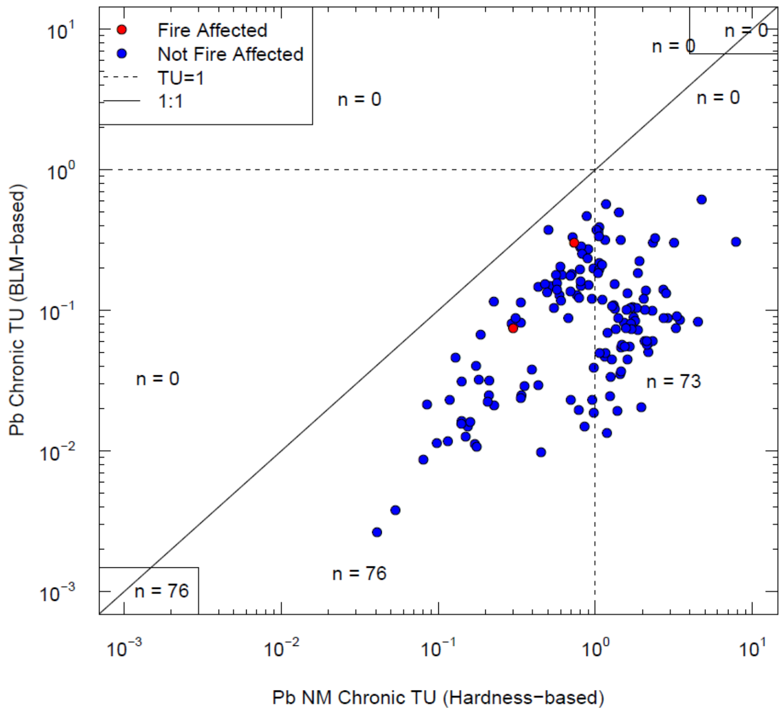


Figure 4-28. Comparison of dissolved <u>lead chronic IWQC</u> TUs based on BLM and New Mexico AWQC for NMAC Class 126 waters

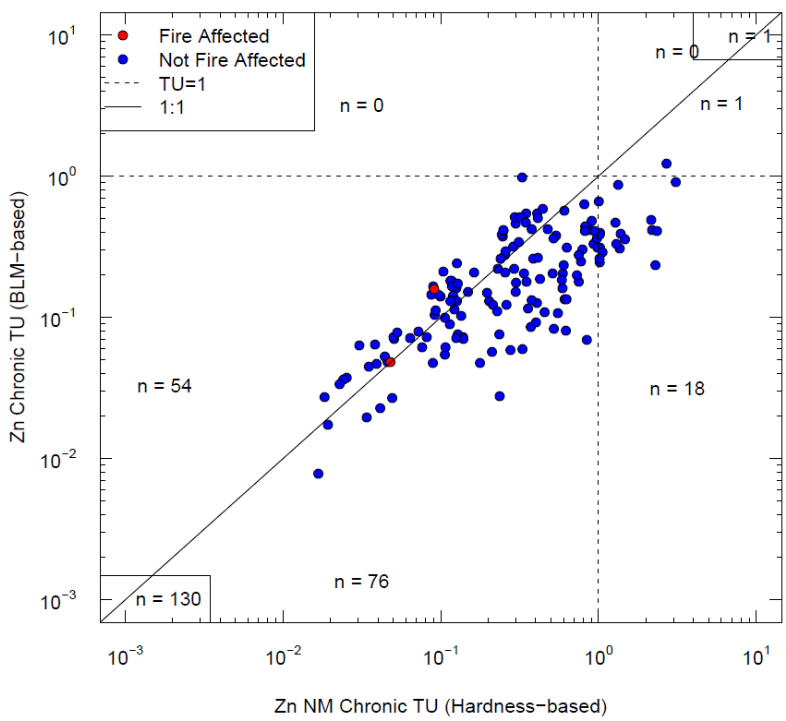


Figure 4-29. Comparison of dissolved <u>zinc chronic IWQC</u> TUs based on BLM and New Mexico AWQC for NMAC Class 126 waters

4.8 IMPLICATIONS OF BLM-BASED IWQC FOR 303(D) LISTINGS

As mentioned in Section 4.3, application of BLM-based AWQC for copper can be expected to result in potentially significant differences for water quality standards compliance determinations versus using hardness-based AWQC, whether for acute or chronic criteria considerations. Such differences for lead and zinc are likely to be less significant for acute criteria but of potential concern for chronic criteria. To illustrate the potentially different outcomes, Table 4-14 compares LANL BLM dataset outcomes for the current and proposed New Mexico §303(d) listings for copper (NMED 2018). For the five new AU segments proposed for Category 5 listings for impairments by copper (acute), results for hardness-based New Mexico TUs support the new listings, while BLM-based TUs show zero incidence of acute BLM-based IWQC exceedances.

Similarly, for the three of seven previously §303(d)-listed AUs, BLM datasets indicate no acute copper IWQC exceedances. Two of the seven listed AUs would probably also pose little to no risk based on the BLM after consideration of BDL copper results used to calculate the TU values. BLM datasets were not available for the remaining two AUs. The Acid Canyon AU previously §303(d)-listed for impairment by zinc is proposed for delisting in 2018, which is supported by results for New Mexico hardness-based and BLM-based IWQC from the current LANL dataset.

As discussed in Sections 4.4-4.6, the Upper Sandia Canyon water quality patterns bear further consideration with regard to BLM outcomes (IWQC and FMBs). The relatively frequent exceedances (48%) of New Mexico acute copper IWQC are in sharp contrast to infrequent (4%) BLM-based IWQC exceedances, which may be limited to particular flow regimes. The acute criteria averaging period for the EPA 2007 BLM-based copper AWQC is 24 hours, which bears consideration for the interplay between the relatively stable baseflow and intermittent, short duration storm water runoff that Upper Sandia canyon experiences, a fairly unique situation with respect to other Pajarito Plateau waters.

Table 4-14. Comparison of IWQC attainment based on BLM and New Mexico IWQC generated for 303(d) Impaired Waters Listings in the LANL vicinity

2016 303(d) listings - NMED 2016, 2018 proposed (adapted from NMED 2018)						2018 LANL BLM DQO/DQA Dataset Basis						
						New Mexico IWQC			BLM-based IWQC			
AU_ID	AU Name	WQS Reference	IMPAIRMENT	IR Category (by AU)	CYCLE FIRST LISTED	n	TU>1	exc freq (%)	n	TU>1	exc freq (%)	Locations
NM-128.A_06	Pajarito Canyon (Two Mile Canyon to Arroyo de La Delfe)	20.6.4.128	COPPER, ACUTE	5/5C	2016	9	7*	78%	9	1*	11%	E243
NM-9000.A_042	Mortandad Canyon (within LANL)	20.6.4.128	COPPER, ACUTE	5/5C	2010	17	7	41%	17	0	0%	E200, E201, E204
NM-9000.A_047	Sandia Canyon (Sigma Canyon to NPDES outfall 001)	20.6.4.126	COPPER, ACUTE	5/5B	2010	128	61	48%	127	4	3%	E121, E122 (2), E123
NM-97.A_002	Acid Canyon (Pueblo to headwaters)	20.6.4.98	COPPER, ACUTE	5/5C	2010	27	1*	4%	27	1*	4%	E055.5, E056
NM-97.A_004	Walnut Canyon (Pueblo Canyon to headwaters)	20.6.4.98	COPPER, ACUTE	5/5C	2014	no data						
NM-97.A_005	Graduation Canyon (Pueblo Canyon to headwaters)	20.6.4.98	COPPER, ACUTE	5/5C	2010	no data						
NM-97.A_029	South Fork Acid Canyon (Acid Canyon to headwaters)	20.6.4.98	COPPER, ACUTE	5/5A	2014	7	0	0%	7	0	0%	E055.5
NM-97.A_029	South Fork Acid Canyon (Acid Canyon to headwaters)	20.6.4.98	ZINC, ACUTE	5/5A	2014	7	0	0%	7	0	0%	E055.5
NM-128.A_14	DP Canyon (Grade control to upper LANL bnd)	20.6.4.128	Copper, Dissolved	5/5C	2018	49	15	31%	49	0	0%	E038, E039.1
NM-9000.A_043	Pueblo Canyon (Acid Canyon to headwaters)	20.6.4.98	Copper, Dissolved	5/5C	2018	13	5	38%	13	0	0%	E055
NM-128.A_16	Arroyo de la Delfe (Pajarito Canyon to headwaters)	20.6.4.128	Copper, Dissolved	5/5C	2018	4	3	75%	4	0	0%	E242.5
NM-128.A_08	Pajarito Canyon (Lower LANL bnd to Two Mile Canyon)	20.6.4.128	Copper, Dissolved	5/5C	2018	18	5	28%	18	0	0%	E245.5, E250
NM-128.A_15	Two Mile Canyon (Pajarito to headwaters)	20.6.4.128	Copper, Dissolved	5/5C	2018	10	5*	50%	10	0	0%	E244

*exceedance uncertain, TUs calculated for non-detects at reported DL, a number of which were 10 µg/L.

5 Discussion, Uncertainty and Other Considerations for Further Use of the BLM DQA Results

This section describes the types of uncertainty encountered and how they may affect key considerations going forward, including but not limited to:

1. Status of BLMs and their acceptance for generating AWQC that meet EPA guidelines
2. IWQC uncertainty with respect to key water quality variables
3. Existing or upcoming New Mexico water quality assessments
4. Spatial groupings of data for FMBs
5. Use of percentiles versus FMBs
6. Potential new IP MTALs

5.1 Status of BLMs and their acceptance for generating AWQC that meet EPA guidelines

To date, EPA has recommended the BLM for use only in generating copper AWQC for freshwater aquatic life, and two states have adopted the BLM as a statewide replacement of hardness-based copper AWQC.[15] However, the BLMs for aluminum, lead, and zinc applied herein have been developed in a manner similar to that used to develop EPA's 2007 nationally recommended copper AWQC. In addition, the aluminum, lead, and zinc BLMs applied herein have been developed and evaluated for the purpose of generating AWQC according to EPA guidelines (e.g., DeForest and Van Genderen 2012; DeForest et al. 2017; Santore et al. 2018). It is not clear if or when EPA will recommend BLM-based AWQC for aluminum, lead, zinc, or other metals. Nonetheless, the lack of an EPA national recommendation does not preclude a state from adopting BLM-based AWQC as a uniform replacement of, or side-by-side alternative to, current hardness-based AWQC, or as SSWQC subject to state agency and EPA review and approval in each case. Additionally, EPA's initial and revised draft "missing parameters" documents (EPA 2012b, 2016) provide an approach that can be used to address not only missing data for copper BLM-based AWQC, but also for the other BLMs given consistent relationships.

Thus, the underpinnings of the BLMs applied herein are sound, state of the science understandings designed to maintain EPA's intended level of protection and provide a potential new and more accurate basis for evaluating not only LANL-area waters but others where suitable datasets exist. This DQO/DQA provides a sound framework for evaluating water quality datasets to generate BLM-based outcomes. The considerable

[15] EPA released draft marine/estuarine AWQC for copper based on the BLM in 2016 (EPA [in prep]).

differences shown between BLM-based AWQC outcomes and those based on current hardness-based AWQC generally suggest that very different surface water quality management decisions might be reached, and that fewer causes for concern would be raised by considering the more accurate BLM-based approaches.

5.2 IWQC UNCERTAINTY WITH RESPECT TO KEY WATER QUALITY VARIABLES

While the dataset used herein to generate BLM-based IWQCs was rich, with respect to BLM input parameters, strategies to address missing values had to be used to maximize usable datasets. Data for pH, which is regarded as a highly important BLM parameter, were available for this dataset, so no estimates of pH were used. However, data for DOC, another sensitive input to the BLM, had to be estimated from TOC in cases where only TOC data were available. In general, estimating DOC from TOC for BLM purposes is a recognized approach, e.g. as used in Oregon (ODEQ 2016a) , and herein was bounded by patterns exhibited in the local dataset. While conservative decisions were made in estimating DOC concentrations, DOC is often an important limitation for application of the BLM. Future monitoring to support BLM application should plan for the collection of complete datasets.

No data existed for temperature in the dataset considered herein, but a temperature sensitivity analysis demonstrated that a conservative assumption of 10°C was appropriate (lower bound of BLM calibration range for temperature input). Temperature has little impact on BLM predictions for copper, lead, and zinc, but it can be important for aluminum (Figure 4-3). To gain a better understanding of the potential broader impacts on decision making from using estimated temperature values for aluminum, further evaluations are needed. The differences in BLM-based acute aluminum IWQC computed at 10°C versus those computed at 15°C appear to be significant and most Pajarito Plateau surface waters are likely to be warmer than 10°C most of the year (e.g., summer monsoonal runoff). The water temperature variable is not included in the MLR proposed by EPA in its 2017 draft aluminum AWQC, so if such AWQC are eventually adopted, the temperature sensitivity issue for aluminum may be moot.

5.3 EXISTING AND UPCOMING NEW MEXICO WATER QUALITY ASSESSMENTS

Employing the BLM to evaluate acute copper IWQC was shown to yield potentially significant differences in assessment outcomes compared to using the current New Mexico hardness-based criteria. The evaluations showed a 36% false positive rate: using hardness-based IWQC would yield an incorrect decision on the status of water quality standard attainment in 36% of the samples. This finding suggests that the 305(b)/303(d) status of current or proposed listings of impairment caused by copper in the LANL area waters may need to be reconsidered in light of the copper BLM-based AWQC. Indeed, based on the proposed 2018 303(d) listings, five additional AUs have been identified as impaired by copper, yet none of the observed copper concentrations exceeded BLM-based acute IWQC for associated locations in the LANL BLM dataset.

The difference was less pronounced for acute zinc IWQC (2% false positive rate), and no errors were apparent for acute lead IWQC. However, the New Mexico hardness-based acute IWQC for lead and zinc tended to yield TUs that were approximately an order of magnitude higher than TUs for BLM-based acute IWQC for these metals (Figures 4-6 and 4-7). These patterns suggest a tendency that might yield significant potential false positives for acute IWQC in other cases where higher observed lead and zinc concentrations might occur. In contrast, chronic IWQC for lead and zinc exhibited pronounced differences between TUs for BLM-based and New Mexico hardness-based IWQC with 49% and 12% false positives, respectively.

Based on visual inspections of the plots contained herein, potentially fire-affected data appear to fall within the overall distributions in the TU quadrant plots and so probably pose little if any impact on potential conclusions that might be reached. However, spatial groupings of BLM datasets should be carefully considered.

5.4 SPATIAL GROUPINGS OF DATA FOR FMBS

For purposes of generating single target values analogous to NPDES WQBELs or sampling benchmarks, like those of the EPA MSGP and LANL IP, the FMBs and median IWQC have merit to the extent that they are sufficiently representative of the key variables involved and projected for the future. The FMB provides an advantage because it explicitly examines observed and projected metal concentrations and exceedance frequencies, while median IWQC are based solely on observed IWQC without regard to observed metals levels or projections. The relatively large datasets for certain canyons yielded robust FMBs and median IWQC that could readily be considered as a new basis for MTALs in the forthcoming LANL IP. The copper acute FMBs for DP, Los Alamos and Pajarito canyons were very similar (13.7 to 14.9 µg/L) and based on relatively large BLM datasets collected over more than a decade and so pooling data for a single FMB for these canyons appears reasonable. However, further consideration of FMBs for Upper Sandia is warranted based on the patterns observed between FMBs and IWQC across the four sampling locations discussed in Section 4.5. An FMB based on data pooled for the four locations appears to be overshadowed by the distinctly different patterns in water quality between baseflow (WS or WP samples representative of stable effluent flow from LANL NPDES outfall 001) versus storm water runoff (WT samples). Further evaluations of pH during the two distinct flow regimes is recommended, as well as considerations for accounting for the acute BLM-based AWQC averaging period (24-hours).

5.5 USE OF HARDNESS-BASED MTALS FOR THE IP

Because the MTALs in the 2015 draft IP depend on hardness results available at the time, i.e. through circa 2014, new hardness data should be evaluated to update those MTALs if BLM-based MTALs or other consideration for use of the BLM is not provided via the IP. For example, compared with the 2015 draft IP hardness basis, median hardness is 66% higher in the current dataset for Canon de Valle, while it is

24% lower for Pajarito canyon. However, the hardness data evaluated herein were limited to those samples that had available BLM datasets so it is not clear if potentially available additional hardness data might further influence updated hardness-based MTALs for copper, lead, zinc and aluminum. In addition, it is not clear whether data richness might affect such considerations (median hardness-based MTALs calculated herein were based on 10 or more samples, while it is not clear for the 2015 draft IP whether sample numbers were taken into account). A relative change in the hardness basis of an MTAL will result in a proportional change in the MTAL calculated on that hardness value and so the uncertainty could have potentially significant impacts on IP compliance decision making.

5.6 POTENTIAL NEW IP MTALS BASED ON THE BLM

The potential impact of the BLM on setting new IP MTALs for copper, lead and zinc is clear (Table 4-12). For copper, BLM-based acute FMBs averaged nearly 3-fold higher, and BLM-based median acute IWQC averaged 5-fold higher than the hardness-based 2015 draft IP MTALs. Similarly, for zinc, both BLM-based alternatives averaged 5-fold higher. And for lead, the BLM-based MTAL alternatives had even greater differences than hardness-based MTALs; averaging 14- to 18-fold higher than the 2015 IP MTALs. In these cases, the FMB-based BLM scenarios may have more merit than median IWQC-based scenarios as IP MTALs because of the greater degree of realism provided by the FMB in terms of its inclusion of exceedance frequency patterns. However, as mentioned above, the sensitivity of the FMB to variability in IWQC and/or TUs for certain locations and spatial groupings appears important and warrants further evaluation. Potential new IP MTALs for aluminum will have to consider the broader issues and considerations posed by 1) sample preparation methods (measurements of unfiltered aluminum are clearly inappropriate for determining compliance), 2) choice of BLM versus the MLR approach proposed by EPA 2017 aluminum AWQC, and 3) aluminum from natural background contributions.

In conclusion, the relatively rich datasets evaluated herein, and the improved accuracy of environmental protection that results from using the BLM appropriately, suggest a distinct ability to make more appropriate decisions and resource allocations than those permitted by hardness-based AWQC, whether for state 305(b)/303(d) assessment purposes or for NPDES permits like the LANL IP.

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Appendices

A. Acute IWQC TU Longitudinal Plots
B. Chronic IWQC TU Longitudinal Plots
C. Acute and Chronic IWQC TU Longitudinal Plots for the Rio Grande
D1. Acute FMBs for Individual Locations
D2. Acute FMBs for Watersheds
E. Chronic IWQC Comparisons in TU Quadrant Diagrams
F. Chronic IWQC Comparisons in TU Quadrant Diagrams for the Rio Grande Dataset