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2003 DRAFT UPDATE OF AMBIENT WATER QUALITY CRITERIA FOR COPPER

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NOTICES

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ACRONYMS

ACR	Acute-Chronic Ratio
BL	Biotic Ligand
BLM	Biotic Ligand Model
CCC	Criterion Continuous Concentration
CF	Conversion Factors
CHESS	Chemical Equilibria in Soils and Solutions
CMC	Criterion Maximum Concentration
CWA	Clean Water Act
DIC	Dissolved Inorganic Carbon
DOC	Dissolved Organic Carbon
DOM	Dissolved Organic Matter
ELS	Early Life Stage
EPA	Environmental Protection Agency
FACR	Final Acute-Chronic Ratio
FAV	Final Acute Value OR Final Accumulation Value
FCV	Final Chronic Value
FIAM	Free Ion Activity Model
GMAV	Genus Mean Acute Value
GSIM	Gill Surface Interaction Model
HA	Humic Acid
LA50	Lethal Level of Accumulation at 50 Percent Effect Level
LOAEC	Lowest Observed Adverse Effect Concentration
Me:BL	Metal-Biotic Ligand Complex
MSE	Mean Square Error
NASQAN	National Stream Quality Accounting Network
NOAEC	No Observed Adverse Effect Concentration
NOM	Natural Organic Matter
PLC	Partial Life-Cycle
SMAV	Species Mean Acute Values
TSS	Total Suspended Solids
WER	Water-Effect Ratio
WET	Whole Effluent Toxicity
WHAM	Windermere Humic Aqueous Model
WQC	Water Quality Criteria

1.0 INTRODUCTION

1.1 Background

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 water from acute and chronic toxic effects from copper. These criteria are based on the latest available scientific information and supersede EPA's previously published recommendations for copper.

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 copper. 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 decisionmakers 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.

1.2 Copper in the Environment

Copper is an abundant trace element found in the earth's crust and is also 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; 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 0.2 to 30 µg/L in freshwater systems (Bowen 1985). Copper concentrations in locations receiving anthropogenic inputs such as mine tailing discharges can vary anywhere from natural background to 100 µg/L (Hem 1989; Lopez and Lee 1977) 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).

1.3 Update of Copper Criteria with the Biotic Ligand Model

The freshwater criteria in this document differ from EPA's previous metals criteria primarily with regard to how metal availability to organisms is addressed. Previous criteria were based on empirical relationships of toxicity to water hardness. These criteria combine the effects of various water quality variables correlated with hardness. Such criteria are most applicable to waters where these correlations were similar to the data set used to derive the relationships. The criteria presented here instead use the biotic ligand model (BLM) (Di Toro et al. 2001). The BLM is based on the premise that toxicity is related to metal bound to a biochemical site (the biotic ligand) and that binding is related to total dissolved metal concentrations and complexing ligands in the water. The complexing ligands compete with the biotic ligand for metals and other cations in the water. Unlike the empirical harness relationships, the BLM explicitly accounts for individual water quality variables, is not linked to a particular correlation among these variables, and can address variables that were not a factor in the hardness relationship.

1.4 Copper Criteria Document Information

Although the new BLM model has now been adopted for use 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 1985 Guidelines (or Guidelines, Stephan et al. 1985). Therefore, it is useful to have some understanding of how the Guidelines are ordinarily applied: (1) Acute toxicity test data must be available for species from a minimum of eight genera with a minimum required taxonomic diversity. The diversity of tested species is intended to ensure protection of various components of an aquatic ecosystem. (2) The final acute value (FAV) is an estimate of the fifth percentile of a sensitivity distribution represented by the average LC50s and EC50s, the Genus Mean Acute Values (GMAVs), of the tested genera. The criterion maximum concentration (CMC) is set to one-half of the FAV to correspond to a lower level of effect than the LC50s/EC50s used to derive the FAV. (3) Chronic toxicity test data (longer term survival, growth, or reproduction) must be available for at least three taxa to derive a final chronic value (FCV). A criterion continuous concentration (CCC) can be established from an FCV calculated similarly to an FAV, if chronic toxicity data are available for eight genera with a minimum required taxonomic diversity; or most often the chronic criterion is set by determining an appropriate acute-chronic ratio (ACR) (the ratio of acutely toxic concentrations to the chronically toxic concentrations) and applying that ratio to the FAV. (4) When necessary, the acute and/or chronic criterion may be lowered to protect recreationally or commercially important species.

The body of this document contains information on acute and chronic toxicity of copper relevant to the derivation of the freshwater and saltwater acute and chronic criteria. It also includes information on the effects of water quality parameters on bioavailability and toxicity of copper as well as some BLM development information. Additional information on the generalized BLM framework, theoretical background, model calibration, and application can be found in the Technical Support Document for the BLM or in the published literature. The data that were reviewed and not used to derive the criteria and other supporting information are also provided in tables and appendices.

2.0 THE CONCEPT OF BIOAVAILABILITY AND REGULATORY APPROACHES FOR COPPER

Copper occurs in natural waters primarily as Cu (II) predominately in complexed form. Free Cu may be present, but is generally a minor species (Stumm and Morgan 1981). Copper reacts with both inorganic and organic chemicals in solution and in suspension, resulting in a multitude of chemical forms. Because the cupric ion is highly reactive, it forms moderate to strongly complexed solutes and precipitates with many inorganic and organic constituents of natural waters (e.g., carbonate, phosphate, and organic materials) and is readily sorbed onto surfaces of suspended solids. Even though it is present in water in many forms, the toxicity of copper to aquatic life has been shown to be related primarily to activity of the cupric ion, and possibly to some of the hydroxy complexes (Allen and Hansen 1996; Andrew 1976; Andrew et al. 1977; Borgmann and Ralph 1983; Chakoumakos et al. 1979; Chapman and McCrady 1977; Dodge and Theis 1979; Howarth and Sprague 1978; Pagenkopf 1983; Petersen 1982; Rueter 1983). Many examples of this classic response of organisms to cupric ion activity, as well as some limited exceptions, are reviewed by Campbell (1995). A formal description of these metal-organism interactions, now commonly referred to as the Free Ion Activity Model (FIAM), was first provided by Morel (1983). Pagenkopf (1983) using a similar approach applied the Gill Surface Interaction Model (GSIM) to predict metal effect levels over a range of water quality characteristics.

Based on the mechanistic principles underlying the BLM, the following general trends of copper toxicity are expected because individual water quality parameters and their combinations are varied among exposure waters. Any changes in water quality that would be expected to decrease the activity of the free copper ion would be expected to decrease the bioavailability of copper. For example, increases in pH, increases in alkalinity, and increases in natural organic matter would all tend to decrease copper bioavailability and would therefore tend to be associated with increased copper LC50 values. Metal bioavailability may also be modified by competitive interactions at the biotic ligand. Increased concentrations of sodium and calcium, for example, can result in reduced binding of copper to physiologically active gill binding sites and can thereby reduce copper bioavailability. Competition with protons is included in the copper model and could result in lower bioavailability at low pH. But these effects occur at relatively lower pH values than are typically used in toxicity tests and, as a result, the primary effect of changing pH is to decrease bioavailability at high pH. Cation competition also has an effect on complexation of Cu by natural organic matter (NOM), and this interaction will to some degree offset competitive interactions that occur at the gill or other sites of action of toxicity.

Historically, aqueous discharges of metals have been regulated based on concentrations of total metal—usually measured as the concentration of total recoverable metal (i.e., the sum of the dissolved metal and the metal that can be liberated from solids during extraction in hot, dilute mineral acid). This regulatory approach was the basis for previous EPA water quality criteria for copper. In 1993, EPA altered the traditional regulatory approach for protection of aquatic life to account for the influence of suspended solids on metal toxicity. EPA authorized States to regulate discharges based on dissolved metal concentration instead of total recoverable metal concentration (Prothro 1993). This change was an attempt to incorporate into the regulatory process the notion that the concentration of dissolved metal better approximates the toxic fraction than does the concentration of total metal (i.e., the presence of suspended solids tends to decrease metal toxicity; see review by Meyer et al. 2002). Nevertheless, a regulatory approach based solely on the concentration of dissolved metal did not address concerns that other water quality parameters besides total suspended solids (TSS) concentration alter metal toxicity.

EPA has already incorporated linear regression equations into criteria calculation procedures to account for decreases of acute and chronic toxicity of copper to freshwater organisms as water hardness increases. However, these regression equations account for other parameters that vary in addition to hardness (at least among some of the data) but do not explicitly account for effects of these other water quality parameters on toxicity.

In response to concerns that the metal criteria did not provide a mechanism to account for the modifying effects of water quality parameters other than hardness on metal toxicity, EPA issued guidance in the early 1980s on the use of a 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). Extensive guidance has been developed on how to evaluate a WER (U.S. EPA 1994). The essence of the approach is as follows. The 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 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, in the water sample collected at a specific location and at a specific time. Although the WER approach remains an important component in establishing site-specific variations to ambient water quality criteria for metals, a complementary approach is needed that (1) explicitly accounts for water quality parameters that modify metal toxicity and (2) can be applied more frequently across spatial and temporal scales.

Because of the influence of water quality parameters such as pH, alkalinity, and organic matter on the formation of compounds that affect the amount of cupric ion present, not all of the copper in the water column contributes directly to toxicity. In other words, not all of the copper appears to be bioavailable. Although the term "bioavailability" eludes a consensus definition (Dickson et al. 1994), in the context of this document it is used to convey the general concept that total Cu (or, more generally, the total concentration of any metal in an exposure water) is not a good predictor of toxicity (Campbell 1995; Meyer 2002; Morel 1983). This concept has led to research and regulatory activity to develop better ways to predict metal toxicity and regulate aqueous discharges (Bergman and Dorward-King 1997; Di Toro et al. 2001; Hamelink et al. 1994; Morel 1983).

2.1 Empirical Models Relating Water Chemistry to Toxicity

Early copper criteria documents (U.S. EPA 1980, 1985, 1996) incorporated linear regression equations into the criterion-calculation procedure to account for attenuation of acute and chronic toxicity of copper to freshwater biota as water hardness increases. Previously though, the only parameter with enough useful data to provide an acceptable predictive capability of copper toxicity was hardness. Temperature ranges were not sufficiently wide with most species, pH values were often not reported or were highly variable, and alkalinity and dissolved organic carbon (DOC) were rarely reported. As a result, criteria for copper, and those for several other metals, were established as functions of water hardness. These equations were determined from meta-analyses in which variables other than hardness varied among at least some of the data sets that were used. Therefore, the regression coefficients for hardness did not only reflect how hardness affected copper toxicity; additionally, hardness was a surrogate for other co-varying water quality parameters not explicitly included in the regression analyses. Moreover, these criteria did not include methods to explicitly account for modifying effects of other water quality parameters when those parameters varied and hardness did not.

An alternate approach that has been proposed to predict metal toxicity is to (1) identify the bioavailable fraction of the metal; (2) analyze or calculate the concentration(s) of the bioavailable form(s) in the exposure water; and (3) predict the toxicity based on an empirical relationship between the biological response and the concentration(s) of the bioavailable form(s). According to this approach, only direct measurement of the concentration of the free metal ion or calculation of its concentration (using a geochemical-speciation model) is needed. Supporting this bioavailable-fraction approach, the concentration of cupric ion is a constant predictor of acute toxicity even in the presence of varying levels of inorganic or organic ligands, which complex copper and alter the cupric ion concentration (i.e., the cupric ion LC50 remains constant even though the concentrations of the ligands differ considerably in different exposure waters) (e.g., Borgmann 1983; Santore et al. 2001). However, this approach is not correct when other cations in the water can interact with the biota. For example, the LC50 of Cu^{2+} increases significantly as the concentration of Ca^{2+} (a major component of water hardness) is increased (Meyer et al. 1999). Thus, the concentration of cupric ion alone is not always sufficient to predict toxicity.

More generally, there is no universally constant bioavailable fraction of a metal that can be identified by chemical analyses (Meyer et al. 2002). The interactions among the abiotic components in the exposure water are important to consider, as well as the interactions of those components with the biota. Hence, although the simple concept of predicting metal toxicity based on the chemical analysis of a bioavailable fraction is qualitatively appealing, in practice, it is quantitatively elusive (Meyer 2002). Instead, the complex interactions of Cu^{2+} with dissolved components, suspended particles, and the biota must be simultaneously considered in order to accurately predict copper toxicity (see Mechanistic Models section).

2.2 Mechanistic Models—Relating Water Chemistry to Toxicity

Although the current water quality criteria for several metals, including copper, are hardness-dependent, it has long been recognized that many other factors affect copper toxicity. The chemical speciation of copper in natural waters and the explanatory power of the free copper ion in determining copper toxicity were first recognized more than 30 years ago (Anderson and Morel 1978; Sunda and Gillespie 1979; Sunda and Guillard 1976; Sunda and Lewis 1978; Zitko et al. 1973). These concepts were eventually formalized in models that linked metal chemistry and biological effects including the gill surface interaction model (GSIM) (Pagenkopf 1983) and the free ion activity model (FIAM) (Morel 1983). Playle and others demonstrated that copper binding to fish gills can be modeled using a chemical speciation approach (Playle et al. 1993a, b). Recently, MacRae and others demonstrated that copper accumulation at the gill shows a dose-response relationship with mortality (MacRae et al. 1999). A more comprehensive review of these historical developments is presented in Paquin et al. (2002).

Although early models showed remarkable utility, several critical issues remained. A considerable amount of information about speciation of metals in the environment has become available and computing techniques have been developed to simulate metal speciation (Nordstrom et al. 1979). Still, the interactions of metals with natural organic matter remained a topic of intense research and debate for the next few decades. Until recently, few available models could predict metal chemistry in the presence of natural organic matter over a range of environmental conditions.

The biotic ligand model is a recent attempt to develop a metal bioavailability model based on the latest chemical and physiological effects information of metals in aquatic environments (Di Toro et al. 2001; Paquin et al. 1999; Santore et al. 2001). The approach was presented to EPA's Science Advisory Board during 1999 and it received a generally favorable response (U.S. EPA 1999, 2000). Like the FIAM and GSIM, the BLM is based on a description of the chemical speciation of metals in aqueous systems (Figure 1). Chemical speciation is simulated as an equilibrium system that includes complexation of inorganic ions and NOM. The chemical system is simulated by the chemical equilibria in soils and solutions (CHESS) model (Santore and Driscoll 1995), including a description of metal interactions with NOM based on the Windermere humic aqueous model (WHAM) (Tipping 1994). A significant advantage

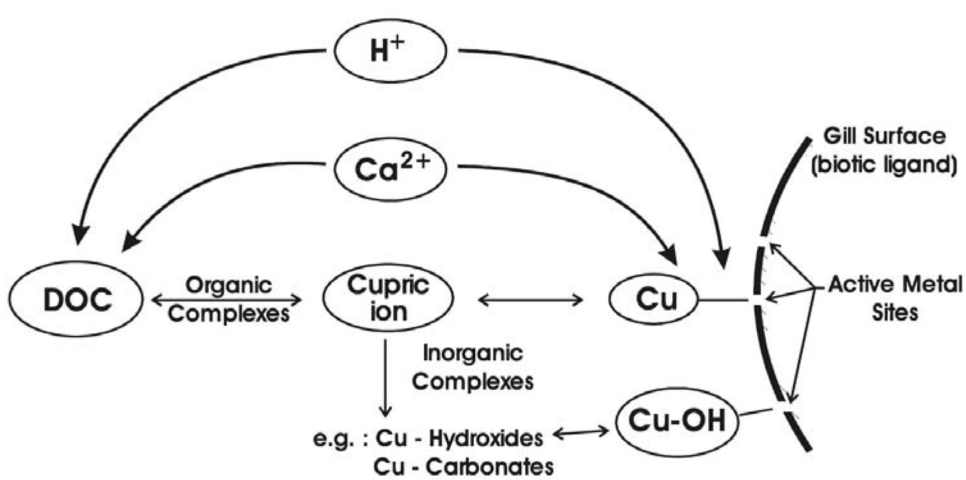

Figure 1. Conceptual Diagram of Copper Speciation and Copper-Gill Model (after Pagenkopf 1983)

of the NOM chemistry developed for WHAM is that reactions and parameter values were developed by simultaneously considering numerous NOM samples and numerous metals.

The BLM also includes reactions that describe the chemical interactions of copper and other cations to physiologically active sites (or "biotic ligands") that correspond to the proximate site of action of toxicity. The model parameters define the degree of interaction based on binding affinity characteristics measured in gill-loading experiments (Playle et al. 1993a, b). That is, the biotic ligand (BL) is represented by a characteristic binding site density and conditional stability constant for each of the dissolved chemical species with which it reacts. Predictions of metal toxicity are made by assuming that the dissolved metal LC50, which varies with water chemistry, is always associated with a fixed critical level of metal accumulation at the biotic ligand. This fixed level of accumulation at 50 percent mortality, referred to as the LA50, is the concentration of the metal-biotic ligand complex (Me:BL) that is associated with 50 percent mortality for a fixed exposure. It is assumed to be constant, regardless of the chemical characteristics of the water (Meyer et al. 1999, 2002). This combination of reactions that describe aqueous metal speciation and organism interactions allows the BLM to predict copper toxicity to a variety of organisms over a variety of water quality conditions (Santore et al. 2001). Appendix A describes the range of water quality values and species to which the model has been applied.

A significant advantage of the BLM is that most of the parameters are invariant for different organisms, despite the complexity of the modeling framework. All of the thermodynamic constants used to simulate inorganic and organic chemical equilibrium reactions are determined by characteristics of the metal and the available ligands. As such, the constants do not change for simulations involving different organisms. Binding constants for copper and other cations to the biotic ligand were developed from data reported by Playle and others using fathead minnow (Playle et al. 1993a, b). Similar measurements would be difficult or impossible to obtain for many organisms, especially invertebrates, because of the difficulty associated with isolating and excising gill tissue, or an appropriate analog. Nevertheless, the parameter values developed from fathead minnow measurements appear to work adequately for other organisms (Santore et al. 2001). Figure 2 shows the predictive capabilities of the model with fathead minnows.

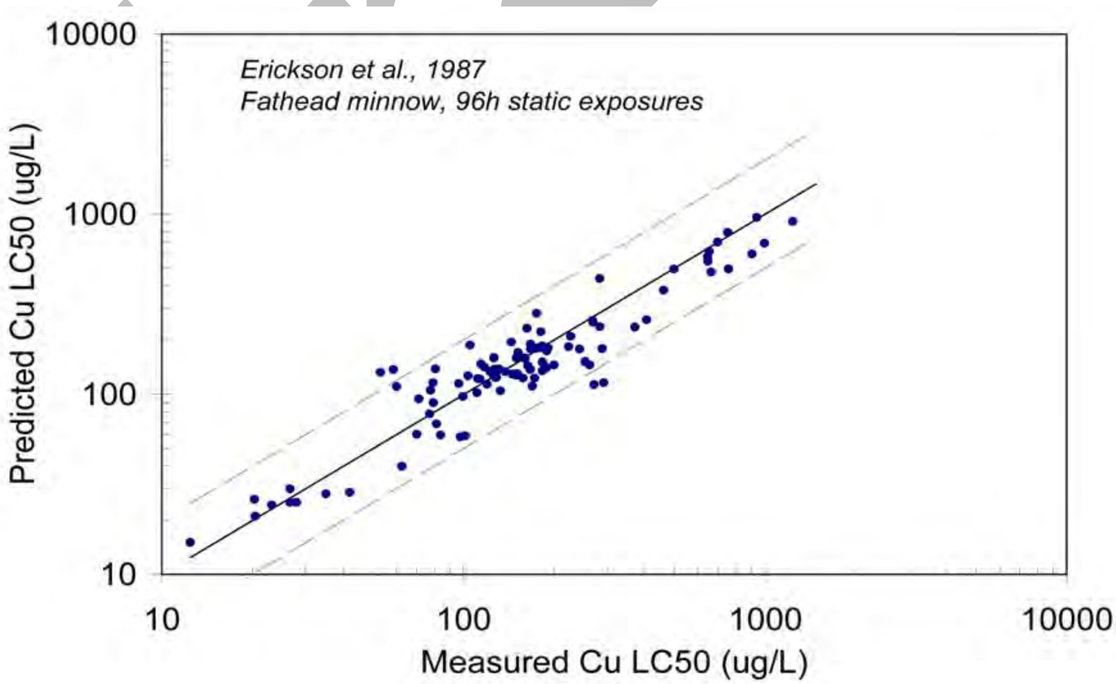

Figure 2. Comparison of Predicted and Measured Acute Copper Toxicity to *P. promelas*

3.0 INCORPORATION OF BLM INTO CRITERIA DEVELOPMENT PROCEDURES

3.1 Implications for Criteria—Criteria Calculations

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 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 may reduce, if not eliminate, the need for site-specific modifications, such as Water Effect Ratios, to account for site-specific chemistry influences on metal toxicity.

While the BLM is currently considered appropriate for use to derive an updated freshwater CMC, further development is required before it will be suitable for use to evaluate a saltwater CMC or a CCC or chronic value.

3.2 BLM Input Parameters

For copper simulations, the necessary water quality input parameters are: pH; dissolved organic carbon (DOC) (in mg/L); percent humic acid; temperature; major cations (Ca^+, Mg^+, Na^+, and K^+); major anions (SO_4^-, Cl^-); dissolved inorganic carbon (DIC); and sulfide.

Dissolved cations compete with Cu^{2+} for dissolved organic matter (DOM) binding sites. For example, pH is important in determining the metal complexation capacity of dissolved organic matter (DOM). It also is important in determining speciation of inorganic carbon, which relates to formation of metal carbonate complexes. DOM can likewise play a critical role in determining metal speciation and bioavailability. Its concentration is entered into the BLM in terms of the concentration of DOC. Because the representation of metal-NOM complexes in the BLM adopted from WHAM, characterizes metal complexation with both humic and fulvic organic matter, it is necessary to specify the distribution of these two humic acid forms of natural organic matter. Ca and Na can directly compete with copper at DOM and biotic ligand binding sites, and these cations will therefore have a direct effect on model predictions. Magnesium may have a critical role as well for some organisms. In that SO_4 may be the dominant anion in freshwater, it is important for determining the charge balance and ionic strength in BLM calculations. Chloride can also contribute to ionic strength computations for copper. The sum of three inorganic species in the BLM—carbonate (CO_3), bicarbonate (HCO_3), and carbonic acid (H_2CO_3)—is considered inorganic carbon. Inorganic carbon is a critical input to the BLM because many metals including copper form carbonate complexes. DIC measurements are typically not made in the environment, so even though it is the preferred measurement, DIC can be estimated from alkalinity and pH when a DIC measurement is not available. Sulfide has a strong affinity for many metals, and although the sulfide concentration is traditionally assumed to be negligible in aerated waters; its concentration may be impacted by wastewater treatment plant effluents.

A number of fixed parameters or constants are also used in the BLM along with the input parameters specified above for speciation or toxicity mode computations. Some of the key fixed constants are the binding constants for the interactions between copper and protons and the "biotic ligand." The values contained in the model were derived by Playle and coworkers by conducting gill-loading experiments (Janes and Playle 1995; Playle et al. 1992, 1993a, b). Playle et al. (1993a, b) also developed the gill site density parameter of 30 nmol/g wet weight used in the model from measured copper gill concentrations.

3.3 Model Prediction Modes

The graphical user interface that has been developed for the BLM allows the user to run the model in either the "Metal Toxicity Mode" or in the "Metal Speciation Mode." Run in the toxicity mode, the BLM predicts the dissolved concentration of copper required to cause acute mortality for water characteristics specified by the user. Run in the speciation mode, the BLM calculates the chemical speciation of a dissolved metal, including complexation with inorganic and organic ligands, and the biotic ligand. Each computational mode requires the user to specify the chemical parameters discussed above and either a dissolved copper concentration or a copper accumulation associated with the biotic ligand.

The biotic ligand represents a discrete receptor or the site of action of toxicity to an organism, where accumulation of metal at or above a critical threshold concentration leads to acute toxicity. The lethal accumulation level on the BL that results in an effect on 50 percent of the individuals is termed the "LA50" for that species. The LA50 concentration of copper on the BL is expected to result in 50 percent mortality in a toxicological exposure for a fixed exposure duration. The LA50 is expressed in units of nmol Cu/g wet weight of the BL. Since the BLM includes inorganic and organic speciation and competitive complexation of copper with the BL, the amount of dissolved copper required to reach this threshold will vary, depending on the water chemistry. Therefore, in addition to calculating chemical speciation, use of the BLM to evaluate the dissolved Cu concentration that is associated with the LA50 provides a prediction of the concentration of copper that would result in acute toxicity (e.g., LC50) for a given set of water quality characteristics.

When run in the metal toxicity mode, the BLM will predict the LC50 of copper using an LA50 value from a parameter file specific to a particular species for all of the observations with a complete set of BLM input parameters. However, the BLM can also be run with "User Defined" LA50s. That is, the BLM will predict LC50s based on the LA50 values specified by the user rather than the default LA50 value specified in the parameter files for particular organisms. Instructions for constructing BLM input files and running the model can be found in the Biotic Ligand Model User's Guide (Appendix B).

3.4 Data Acceptability and Screening Procedures

Data screening procedures for this effort differed from data screening procedures for previous copper criteria documents, in that studies previously considered unacceptable for deriving criteria are acceptable when utilizing the BLM. For example, studies with DOC content exceeding 5 mg/L or studies that were fed were not always acceptable in the past, but are now acceptable for use with the BLM, because the BLM is designed to account for these differences. Conversely, some previously acceptable freshwater acute toxicity tests were relegated to Appendix C (other data) because of poor chemical characterization, together with several other freshwater tests in which copper concentrations in the test chambers were not measured. Detailed chemical analyses of the dilution water, test water, and measured copper concentrations are critical parameters for the BLM (see Mechanistic Models section). The lack of any or all of these major ion concentrations, including measurements of total or dissolved copper, without reliable estimates of surrogate values, precludes the use of a particular study's results (see next section, Estimation of Test Water Chemistry).

3.5 Estimation of Test Water Chemistry

To incorporate the BLM into the copper aquatic life criteria document, a data table was generated summarizing the acute toxicity of copper to freshwater organisms that included the necessary BLM water chemistry parameters. Studies lacking measured copper concentrations were not considered for further evaluation. A literature review was conducted, searching AQUIRE, BIOSYS, and CAS. The literature was reviewed, and the appropriate measurements were tabulated.

As the understanding by the scientific community of the important influence of water chemistry on metals toxicity has increased, measurements (and reporting) of relevant water quality parameters has also increased. Still, much of the currently available aquatic toxicity literature for metals does not include measurements for all of the key BLM inputs. Many of these key BLM inputs were not measured or reported in the published material reviewed for this update of the WQC. Consequently, additional data were obtained from the authors; additional measurements were made in relevant water sources; or, finally, input parameters were estimated. A detailed description of the methods used to obtain or estimate these input parameters is included in *Estimation of Water Chemistry Parameters for Acute Copper Toxicity Tests* (Appendix D). Below is a summary of the effort undertaken to estimate the various test water chemistry conditions.

3.6 Water Chemistry Data Acquisition

Studies included in Table 1a of the ambient water quality criteria document for copper were reviewed to record all reported information on dilution and test water chemistry. Any additional references to which the authors referred while describing their test waters were retrieved. When critical water chemistry parameters were not available, authors were asked to measure missing water chemistry parameters in the toxicity test 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 had been conducted. Failing this, the U.S. Geological Survey National Stream Quality Accounting Network (NASQAN) and the EPA STOrage and RETrieval (STORET) data were used to obtain data for tests conducted in ambient surface water. Where actual water chemistry data were unavailable, data from other studies with the same water were used as surrogate values if appropriate. In some instances, other available sources were contacted to obtain water chemistry data (e.g., city drinking water treatment officials). 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 input parameters were based on the reported hardness measurement and regression relationships constructed for various input parameters from NASQAN data.

As with any modeling effort, the reliability of model output depends on the reliability of model input. Although the input data have been carefully scrutinized and filtered, the reliability of the BLM-derived accumulation and toxicity values for this project are subject to the limitations of the input measurements and estimation procedures described above.

3.7 Ranking of Quality of Test Chemistry Characterization

A ranking system was devised to evaluate only the quality of the chemical characterization of the test water, not the overall quality of the study itself. 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 were not used in the criteria development procedures because the estimates for some of the key input parameters were not thought to be reliable.

3.8 Criteria Computations

To calculate the acute criterion or CMC, reported acute toxicity values (e.g., LC50s) (Table 1a) and individual test water chemistry parameters were used to calculate LA50 values by running the model in the speciation mode. These LA50 values were then normalized to a standard water condition (Table 1a, footnote d) by running the model in the toxicity mode and specifying user-defined LA50s. As used here, "normalization" refers to the procedure whereby all of the measured effect levels were adjusted, via use of the BLM, to the predicted LC50 that would have been expected in a standard test water. These normalized LC50s were used to calculate Species Mean Acute Values (SMAVs), Genus Mean Acute Values (GMAVs), and a Final Acute Value (FAV) pursuant to the 1985 Guidelines procedure. The FAV represents a hypothetical genus more sensitive than 95 percent of the tested genera. The FAV was derived from the four GMAVs that have cumulative probabilities closest to the 5th percentile toxicity value for all the tested genera (Table 3a). Inputting this FAV as an LC50 concentration and running the model in speciation mode determines the lethal accumulation associated with the FAV in the standard test water. Since it is assumed that the LA50 does not vary with changes in water chemistry, this LA50 is programmed into the model as a constant. To derive a criterion for a specific site, the site water chemistry data are input to the model. The model then uses an iterative approach to determine the dissolved copper concentration needed to achieve a Cu-biotic ligand concentration equal to the criterion LA50. This dissolved Cu concentration is in effect the FAV based on site water chemistry. The site-specific CMC is this predicted dissolved metal concentration divided by two. The site-specific CCC is the CMC divided by the final acute-chronic ratio (FACR).

The LA50s used in criteria computations were calculated for each test in which water quality characteristics could be reasonably well characterized. Because an underlying premise of the BLM is that the LA50 is invariant for a given organism, for any test condition, the fact that some residual variability in LA50s exists may reflect model uncertainty, including: (1) among-strain variability; (2) among-life-stage variability; and (3) potential physiological effects of the site water on the test organism that alter organism sensitivity rather than metal bioavailability.

Ultimately, the final freshwater criteria depend on a number of varying water quality parameters (e.g., Ca^{+}, Mg^{+}, and DOC), and any number of test water chemistries could be used to normalize the Table 1a data. Table 1a data (LC50s and EC50s) are standardized to the water chemistry condition specified in footnote f, for illustrative purposes only as is typical in hardness-dependent metals criteria documents. Be that as it may, the normalization chemistry selected may influence the species sensitivity distribution, particularly when two or more species have similar sensitivities to copper toxicity. Example criteria for several water chemistry conditions are provided in Figure 6.

4.0 CONVERSION FACTORS

Although past water quality criteria for copper (and other metals) had been established upon total metals' concentrations, EPA made the decision to allow the expression of metals criteria on the basis of dissolved metal (operationally defined as metal that passes through a 0.45-micron filter, [U.S. EPA 1993]) because it was thought to better represent the bioavailable fraction of the metal. At that time, most data in existing databases were from tests that were either conducted using nominal concentrations, or provided only total copper measurements, such that some procedure was required to estimate their dissolved equivalents. Now, dissolved metals toxicity values are required as BLM input in order to obtain lethal accumulation values. EPA used conversion factors (CF) that when multiplied by the total metal concentrations result in a dissolved metal concentration. CF corresponds to the percentage of the total recoverable metal that is dissolved.

CFs for the conversion of total copper concentrations in water from freshwater toxicity tests to dissolved copper concentrations were developed by conducting a number of laboratory toxicity tests (Stephan 1995; University of Wisconsin-Superior 1995). Simulation tests were conducted to determine the influence of copper concentrations, presence or absence of food, duration of the test, hardness, and species of test organism on the concentration of dissolved copper in the test water. The simulation tests were designed to mimic conditions that existed during the toxicity tests used to derive the earlier metals criteria, such as sorption of metal onto test chambers, uptake of metal by test organisms, and precipitation. The recommended conversion factors from the Stephan (1995) report (0.96 for both the CMC and CCC) were utilized to convert total recoverable measurements to dissolved values, when necessary.

In the case of saltwater, several studies are available that report nominal, total, and dissolved concentrations of copper in laboratory water (Table 1b) from site-specific WER studies (refer to Appendix E for further details). These studies show relatively consistent ratios for the nominal-to-dissolved concentrations and for total-to-dissolved concentrations. The dissolved-to-nominal conversion requires a larger correction factor than does the dissolved-to-total correction. The data provided in Appendix E bear this out in all but one case (SAIC 1993 data for the blue mussel). Nominal copper concentrations for this series of tests may have been overstated or the measured total copper concentrations may have been proportionally lower than for the other studies. The overall ratio for correcting saltwater total copper concentrations to dissolved copper concentrations is 0.909, based on the results of six studies (Appendix E). This is comparable to its equivalent conversion factor in freshwater, which is 0.960 (Stephan 1995). When it is necessary to convert nominal saltwater copper concentrations to dissolved copper concentrations, the conversion factor is 0.838 based on the same six studies.

5.0 DATA SUMMARY AND CRITERIA CALCULATION

5.1 Summary of Acute Toxicity to Freshwater Animals and Criteria Calculation

This effort identified approximately 600 acute freshwater toxicity tests with aquatic organisms and copper considered acceptable for deriving criteria. Of these acceptable studies, approximately 100 were eliminated from the criteria derivation process because they did not report measured copper concentrations. Nearly 150 additional studies were eliminated from the calculation of the FAV because they received a quality rating of greater than 4 in the quality rating scheme described above.

The BLM version AP08-Build 2002-05-07 was used to calculate lethal accumulation values for each individual test result included in Table 1a by running the model in the metal speciation mode (see Appendix B, BLM User's Guide). Reported effect levels (i.e., LC50s or EC50s) and the chemistry characterization for each test were input parameters for the model (Appendix F). LC50s or EC50s reported in terms of total recoverable metal were converted to dissolved concentrations as discussed above in the Conversion Factors section. Lethal accumulation values were then converted to toxicity values (e.g., LC50s) at standard water condition by running the model in the metal toxicity mode.

Data from approximately 350 test were used to derive normalized LC50 values, including 15 species of invertebrates, 22 species of fish, and 1 amphibian species (Table 1a). Large variations in toxicity values were observed for some species. Examination of the nature of these individual values showed that a majority of them corresponded to observations where key BLM parameters were missing and thus estimated (i.e., a quality ranking of 3 or 4 range is typical for these values), and for many species the variation in LC50 was seen to increase in observations with more missing BLM parameters (e.g., *D. magna*, Figure 3). The large variability in LC50 for some species, therefore, seems to be related to the use of estimated BLM parameters for some of the data. For other organisms (such as rainbow trout), significant variations in LC50s were likely due to the mixture of life-stages represented in the acute toxicity datasets. In general, an objective approach that could be used to automatically screen anomalous LC50 values was needed. For a given species with more than five test results, relatively extreme values

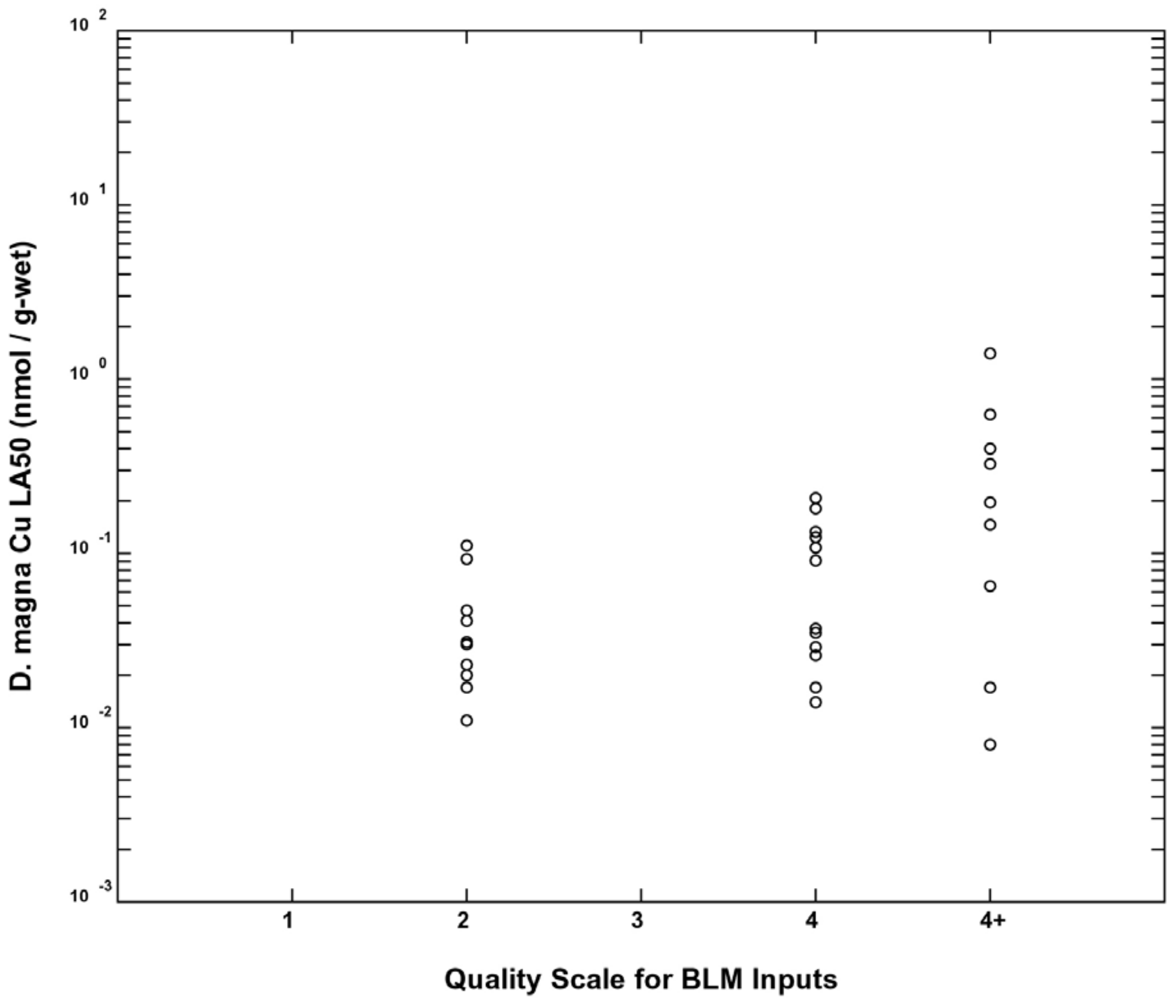

Figure 3. Quality Scale for *D. magna* BLM Input Data

were defined within the distribution of LC50 values using a simple statistical method that identifies those individual values that are far from most of the rest of the population of values (Chambers et al. 1983). To characterize these extreme values, a range was established by first calculating the difference between the 1st and 3rd quartiles for the entire dataset. This difference was then multiplied by 1.5 and either added to the 3rd quartile, or subtracted from the 1st quartile to establish the “inside range.” Any points falling outside this range were identified as extreme values. While data limitations preclude the application of a more formal evaluation of “statistical outliers,” this simplified procedure was considered to be a reasonable way to account for what appeared to be anomalous results.

As an example of this method applied to the LC50 data, box plots are shown of the range of LC50 values for each of the species in Table 1a. Species are identified with numbers, as shown in Table 6. For each species, the geometric mean is shown as the center symbol, the first set of ranges represent the 1st and 3rd quartile. The second set of ranges represent the minimum and maximum values excluding extreme values. Data corresponding to extreme values are individually plotted as separate plotting symbols (Figure 4). For the extreme values, the number of vertices in the plotting symbol represents the

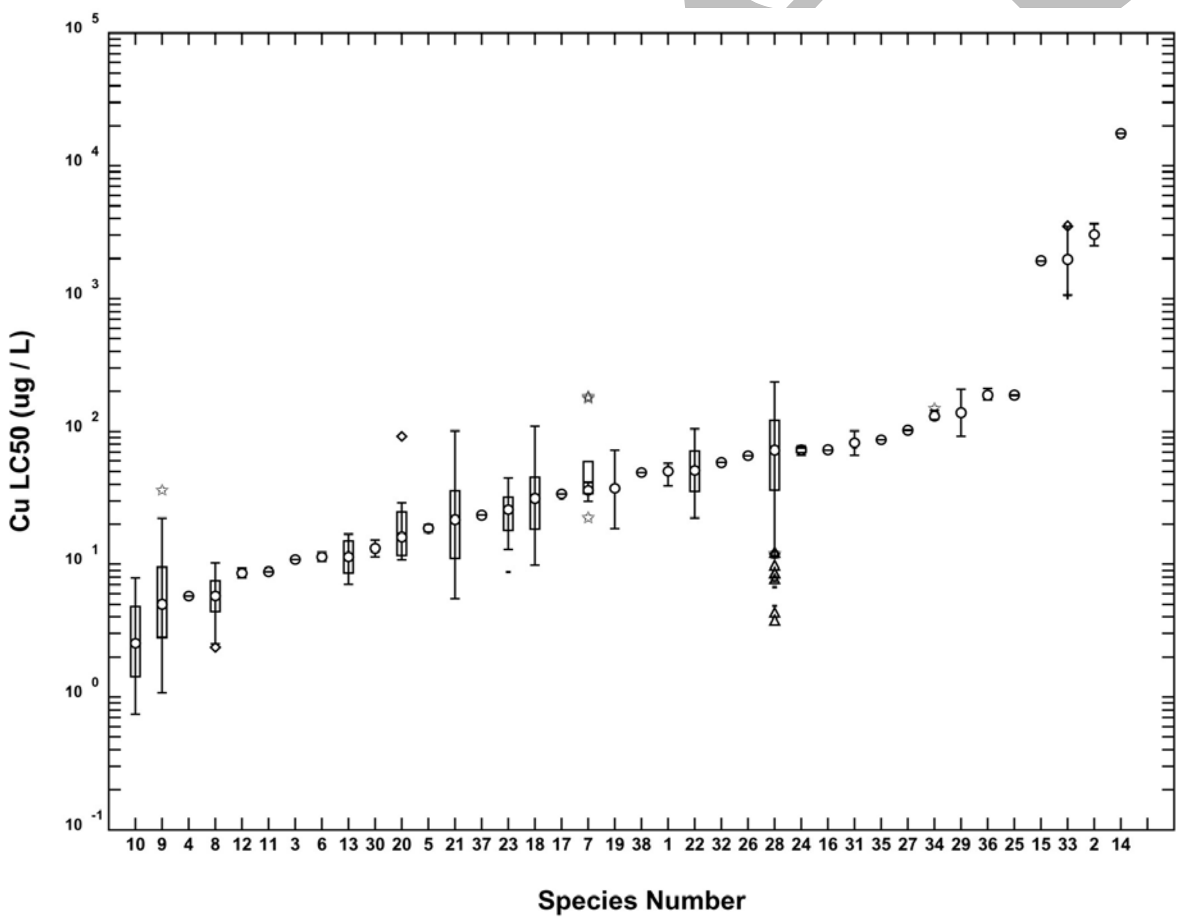

Figure 4. Ranges and Distribution of Normalized LC50 Values for Species Listed in Table 1

Species are identified by unique species number listed in Table 6. For each species the range between the 1st and 3rd quartile of all available normalized LC50 values is represented by the box. Extreme values are plotted as individual symbols, with the number of vertices indicating the quality scale (extreme values and quality scales are discussed in Section 5.1). Statistics shown for normalized LC50 values after excluding extreme values include the geometric mean shown as a circle, and minimum and maximum values shown as whisker bars around the mean.

quality ranking (e.g., a triangle represents an observation with a quality ranking of three, a diamond represents an observation with a quality ranking of 4+, a star represents a quality ranking of 4 or 4-). The LC50 values that corresponded to “extreme values” were therefore not considered in subsequent calculation of the 5th-percentile LC50 value.

SMAVs ranged from 2.54 µg/L for the most sensitive species, *Daphnia pulicaria*, to 101,999 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 3.56 µg/L for *Daphnids* to 101,999 µg/L for the *Notemigonus* genus. Nine of the 10 most sensitive genera were invertebrates. The salmonid genus *Oncorhynchus* was the most sensitive fish genus, with a GMAV of 29.11 µg/L and an overall GMAV ranking of 10.

Toxicity values are available for more than one species in eight different taxonomic families. The ranked GMAVs are presented in Figure 5. Pursuant to procedures used to calculate a FAV, a FAV of 4.2 :g/L was derived from the four GMAVs with cumulative probabilities closest to the 5th percentile toxicity value for all the tested genera (Table 3c). The presumption is that this acute toxicity value represents the LC50 for an organism that is sensitive at the 5 percentile level of the GMAV distribution. The four lowest GMAVs vary by less than a factor of three from the highest to the lowest value. The CMC is the FAV divided by two, and rounded to two significant figures. Therefore, the freshwater dissolved copper CMC for the normalization chemistry presented is 2.1 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 6.

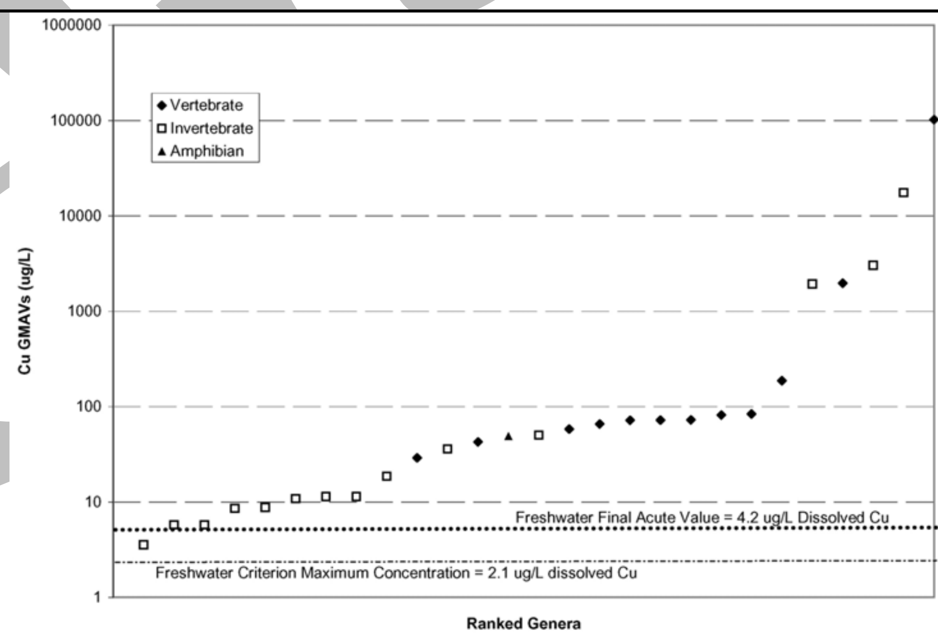

Figure 5. Ranked Freshwater Genus Mean Acute Values (GMAVs)

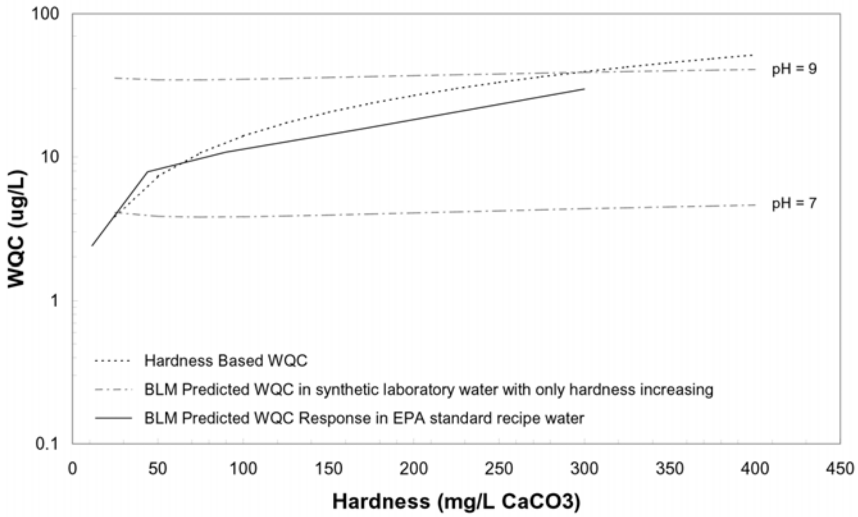

Figure 6. Comparison of Existing Hardness Based WQC and BLM Based WQC in Synthetic Laboratory Water and EPA Standard Recipe Water for DOC = 2.3 mg/L

5.1.1 *Comparison With Hardness-Adjusted Values*

As discussed previously, 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. While in principle the BLM is expected to improve the criteria calculation method, the BLM's ability to accurately predict LC50s or metal speciation is limited by the quality of the input data. For this effort, many input parameters were estimated. To ascertain if the BLM-based criterion is an improvement over a hardness-dependent criterion in light of the necessity of estimating several of the required input parameters, the variations between measured versus predicted values for each of these approaches were compared.

For the first comparison, lethal accumulation values were calculated for each study result (uncensored data) utilizing the measured or estimated chemistry input parameters. Average accumulation values for each species were calculated and used to run the BLM with "User Defined" LA50s, specifying the species average accumulation value for all study results for that species and the original input chemistry parameters. The predicted LC50 values at each chemistry condition were compared with the originally measured values by regressing the natural logarithm of the predicted toxicity value versus the natural logarithm of the measured toxicity value.

A similar procedure was performed for the hardness adjustment. A pooled hardness slope was calculated using all appropriate Table 1a data (considering all quality ratings) based on the 1985 Guideline procedure (Appendix G). This pooled slope was used to normalize all Table 1a data used for the BLM analysis to a standard hardness of 50 mg/L (measured as $CaCO_3$). Species mean acute values were calculated and used to predict LC50s for each test result, for that same species, at the test hardness. Again, the natural logarithms of the measured versus hardness predicted values were regressed.

The mean square of error (MSE) from these two least squares regression procedures were compared. The MSE from the BLM measured versus predicted analysis (0.403) was only slightly lower than the MSE from the comparable hardness analysis (0.420). The small reduction in the MSE for the BLM analysis is interpreted to mean that the BLM, in this case, was a slightly better predictor of LC50 values and somewhat better at reducing variability among species mean values compared with the hardness adjustment for these laboratory water studies. 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.

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 recipes 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 was used to predict the WQC with a DOC concentration of 2.3 mg/L (the average value in the data used in Table 1) for the five standard hardness waters. The BLM criterion for these waters agrees very well with that calculated by the hardness equation used in previous copper criterion documents (Figure 6). 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). Also shown in Figure 6 are BLM predictions with only hardness varying. As can be seen, these predictions show a much flatter response with increasing hardness, and do not match the response seen in the hardness equation at all. The hardness equation, therefore, 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.

5.2 Summary of Acute Toxicity to Saltwater Animals and Criteria Calculation

Tests of the acute toxicity of copper to saltwater organisms (acceptable for deriving criteria) have been conducted with 34 species of invertebrates and 18 species of fish (Table 1b). In general, where relationships were apparent between life stage and sensitivity, values only for the most sensitive life stage were considered in deriving SMAVs. The censoring procedure used for the freshwater toxicity values was also considered for use in censoring saltwater acute toxicity values. However, it was not applied. The freshwater censoring procedure was not used because, in one case, it resulted in eliminating only data for the most sensitive life-stage, rather than the insensitive life-stage. In situations where data indicate that a particular life-stage for the species is at least a factor or two more resistant than another, the Guidelines recommend that the data for the more resistant life-stage not be used in the calculation of the SMAV.

Embryo-larval life-stages of bivalve mollusc genera represent the first two of the four most sensitive genera, including, by sensitivity rank, the genera *Mytilus*-11.5 µg/L and *Crassostrea*-12.6 µg/L. Toxicity data for *Mytilus edulis* were distinguished from data for *Mytilus spp*. based on the molecular genetics work presented by Gaffney (1997) and information about the collection locations of the test organisms for the *Mytilus* studies. The fourth most sensitive genera (the sea urchin genus *Strongylocentrotus*) is also represented by the embryo-larval life-stage (Table 1b). Comparing the data for older mussels (Nelson et al. 1988) and oysters (Okazaki 1976) with data for embryo-larval forms indicates that these early life stages (ELSs) are appreciably more sensitive than the older forms. This is probably true for marine invertebrates in general, although data for the red abalone (Martin et al. 1977) indicate that 48-hour larvae are perhaps slightly more resistant than larger forms. The mysid, *Holmesimysis costata*, and the copepods, *Eurytemora affinis* and *Acartia tonsa*, are among the most sensitive crustacean species tested.

Except for the summer flounder and the cabezon, with GMAVs of 12.7 and 86.4 µg/L, respectively, no other saltwater fish had a GMAV below 100 µg/L. Fourteen other genera of marine fish had GMAVs from 117 to 4,743 µg/L dissolved copper. Two of the lowest fish GMAVs were based on tests with early life stages, and the higher fish GMAVs did not include tests with early life stages. These results suggest that acute tests with early (post-hatch) life stages can generally be protective of acute toxicity to older life stages, but not necessarily the reverse.

In sum, several studies indicate that salinity affects copper toxicity and those effects are species-dependent. The brackish water clam, *Rangia cuneata*, was very sensitive to copper in freshwater (LC50 210 µg/L at <1 g/kg salinity), but 35 to 38 times more resistant at salinities of 5.5 and 22 g/kg (Olson and Harrel 1973). Similarly, young striped bass were about three times more sensitive to copper at a salinity of 5 g/kg than at 10 or 15 g/kg (Reardon and Harrel 1990). An influence of salinity was observed by Ozoh (1992a) in the previously cited study of the influence of temperature and salinity on copper toxicity to the polychaete worm, *Hediste diversicolor*. Effects of salinity were more consistent than those for temperature. A regression of log LC50 versus log salinity indicated a slope of 0.245 for young worms, and a slope of 0.596 for mature worms. Increasing salinity over the range tested (7–30 g/kg) increased LC50s by factors of approximately 1.4 and 2.4 for young worms and mature worms, respectively. Establishing salinity-dependent criteria on the basis of these limited data is not possible. Furthermore, salinity-based criteria should be based only on tests with organisms and life stages that would be present at lower salinities.

Acute values are available for more than one species in the eight different taxonomic families recommended in the Guidelines. The 44 available saltwater GMAVs ranged from 11.5 µg/L dissolved copper for *Mytilus* to 6,448 µg/L for *Rangia*, a factor of over 500 difference (Table 3b, Figure 7). In each of six genera with a range of SMAVs, all SMAVs within the genus are within a factor of 3.5. A saltwater FAV of 12.3 µg/L dissolved copper was obtained using the four lowest GMAVs in Table 3b and the calculation procedure described in the Guidelines. This FAV was lowered to 6.19 µg/L to protect commercially and recreationally important mussel species. The CMC is the FAV divided by two, and rounded to two significant figures. Therefore, the new saltwater dissolved copper CMC is 3.1 µg/L.

5.3 Formulation of the CCC

5.3.1 *Statistical 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 (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

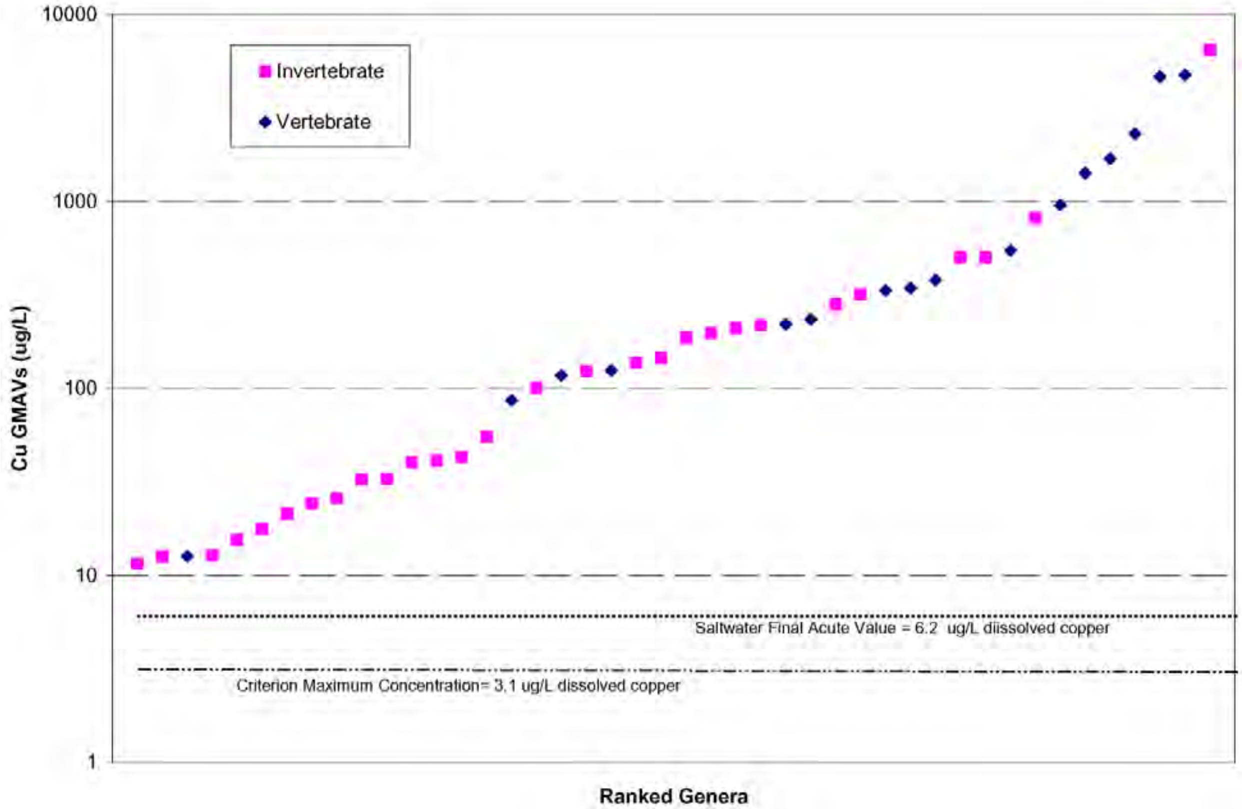

Figure 7. Ranked Saltwater Genus Mean Acute Values (GMAVs)

approach, however, has limitations; it 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 calculate chronic values focuses on the use of point estimates such as 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 relatively small effect, for example 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, is rarely 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.

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). 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, was not available, or did not lend itself to regression analysis, best scientific judgment was used to determine the chronic value. In this case, the chronic value is usually the geometric mean of the NOAEC and the LOAEC. But when no treatment concentration was an NOAEC, the chronic value was 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 selected, for the most part, 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 H. Figures that presents the data and regression/probability distribution line for each of the acceptable chronic test which contained sufficient acceptable data are also provided in Appendix H.

5.3.2 *Calculation of Freshwater CCC*

Acceptable freshwater chronic toxicity data from early life stage tests, partial life-cycle tests, and full life-cycle tests are currently 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 17 of the tests (Table 2c). The relationship between acute toxicity values and ACRs is presented in Figure 8. The supporting acute and chronic test values for the ACRs and the species mean ACRs are presented in Table 3c.

The general effect of hardness on chronic toxicity is not evident upon inspection of the limited hardness-chronic toxicity data for the species for which such evaluations are marginally possible. Five tests over a range of hardness values were conducted with *D. magna* (Blaylock et al. 1985; Chapman et al. unpublished manuscript; van Leeuwen et al. 1988). Five tests over a range of hardness values were also conducted with *C. dubia* (Belanger et al. 1989; Carlson et al. 1986; Oris et al. 1991). Winner (1985) conducted eight tests with *D. pulex* over a range of hardness values, but humic acid was also varied in these tests. In the *D. magna* tests, chronic values increased when hardness increased from about 50 to about 100 mg/L; however, in one of the tests, the chronic value decreased when hardness was further raised to about 200 mg/L. In a second test conducted at a hardness of 225 mg/L, the chronic value was not much higher than those in the 100 mg/L hardness tests. The resulting overall slope for *D. magna* based on these data is negative. The *C. dubia* test exhibited no discernible trends between hardness and toxicity. One possibility is that daphnids may be ingesting precipitated copper that might form at high hardness and high pH. Alternatively, Winner et al. (1985) suggest that Ca^{2+} and Mg^{2+} ions in hard water may be displacing Cu^{2+} from binding sites on humic acid, making more copper bioavailable. Because the hardness relationship with chronic toxicity is equivocal, no overall chronic slope was derived.

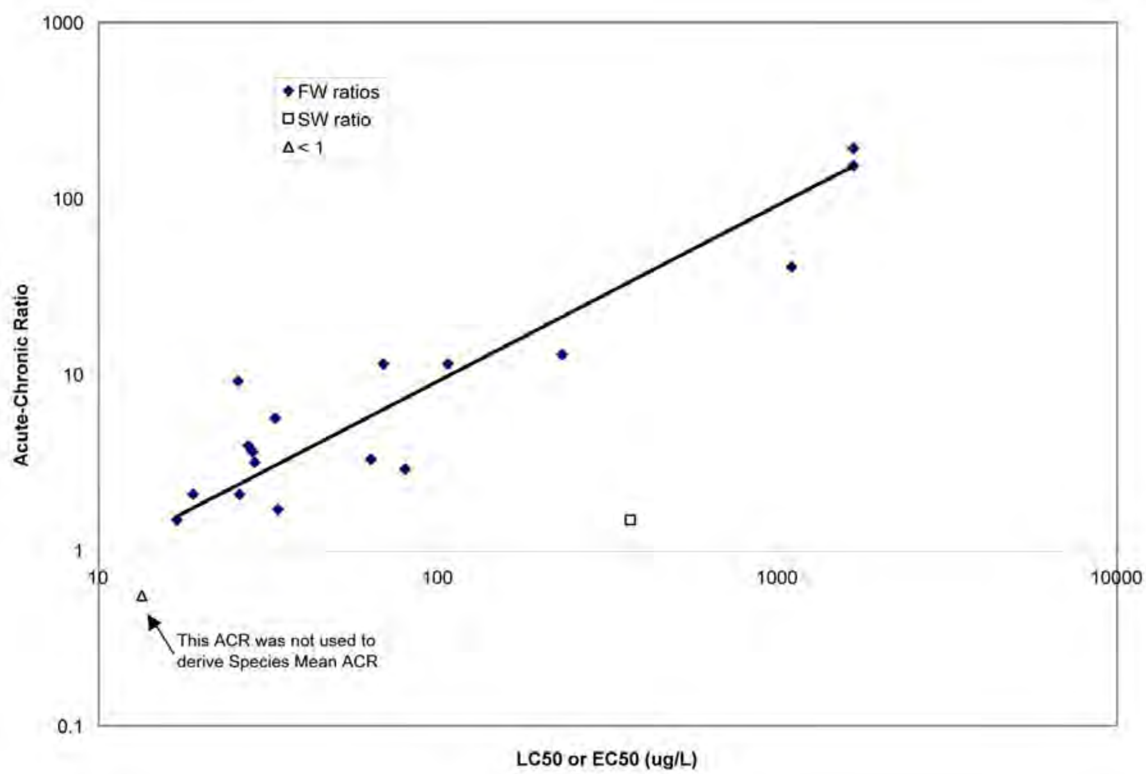

Figure 8. Relationship Between Freshwater Acute Copper Sensitivity (LC50 or EC50) and Acute-Chronic Ratios

Because the minimum eight family data requirements for chronic toxicity data were not met in order to use the FAV approach and because the relationship between hardness and chronic toxicity is equivocal, EPA elected to derive the CCC utilizing the ACR approach from the Guidelines. Moreover, this was a means of incorporating the improvements of the acute BLM calculations into the chronic criterion derivation procedures even though, as previously mentioned, additional development is required before the BLM will be suitable for use in evaluating chronic toxicity data directly. To calculate the FCV, the FAV is divided by the FACR; thus, no chronic hardness slope is necessary to derive a CCC.

The freshwater FCV is derived using acute chronic ratios in conjunction with the FAV. However, the FAV is site-water specific. To derive a FCV, the BLM is run in the toxicity mode, which utilizes the accumulation value constant incorporated in the model to calculate an LC50 based on the site water chemistry composition. This LC50 is then divided by the freshwater FACR to generate an FCV, which is the basis for the CCC.

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*. The FACR of 3.23 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*. Pursuant to the Guidelines, 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 acutely sensitive species and increases in ACRs as sensitivity decreased, the FACR was derived from data for species whose SMAVs were close to the FAV. Based on the normalization water chemistry conditions used for illustrative purposes in the document, the freshwater CMC value is 4.2, which divided by the FACR of 3.23 results in a freshwater CCC of 1.3 µg/L dissolved Cu.

5.3.3 *Evaluation of the Chronic Data Available for Saltwater Species*

Only one acceptable saltwater chronic copper value is available for the sheepshead minnow (Table 2b). This chronic toxicity value was obtained from a flow-through early life stage test in which the concentrations of copper in the test chamber were measured.

The ELS test with sheepshead minnow was one of the tests for which the chronic value and most sensitive effect are reported without providing concentration-response data. Thus, regression analysis was not an option for statistical evaluation of the data in this case. In the 28-day ELS test, growth was reported to be a more sensitive endpoint than mortality, and the chronic value for growth was 249 µg/L. The 96-hour LC50 reported for copper in this study was 368 µg/L, and the two values provide an acute-chronic ratio of 1.48.

A life-cycle test was conducted with the mysid, *Americamysis bahia* (formerly *Mysidopsis bahia*). Survival of mysids was reduced at 140 µg/L, and production of young virtually ceased at 77 µg/L (significant at $P<0.05$), but reproduction at 24 and 38 µg/L was not different from that of controls. Based on reproductive data, unacceptable effects were observed at 77 µg/L, but not at 38 µg/L, resulting in a chronic value of 54.09 µg/L. Using the acute value of 181 µg/L, an ACR for this mysid would be 3.346. Control survival in this test however, was considered inadequate; thus, the chronic value was not used to derive the final chronic criterion.

The ACR value for saltwater is for a relatively acutely insensitive saltwater species, with a GMAV falling in the upper half of all tested saltwater genera. The lowest saltwater acute values are from tests with embryos and larvae of molluscs and embryos of summer flounder, which are possibly the most sensitive life stages of these species. Although saltwater ACRs for acutely sensitive saltwater species are not available, ACRs for acutely sensitive freshwater species are available. Some of the most acutely sensitive freshwater species for which ACRs are available are cladocerans *C. dubia*, *D. magna*, and *D. pulex*). (Data for *D. pulex* are not listed in Table 1a because of the ranking based on the chemical characterization of the test water for the BLM. *D. pulex* would be among the most acutely sensitive species if a hardness adjustment were utilized instead of the BLM.) On the basis of data for the five sensitive freshwater species along with the one available saltwater ACR for the sheepshead minnow, the saltwater FACR is the same as the freshwater ACR of 3.23. Thus, for saltwater, the final chronic value for copper is equal to the FAV of 6.188 µg/L divided by the ACR of 3.23, or 1.9 µg/L (Table 3c).

6.0 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 4a, b) 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 (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 6).

Data are available on the toxicity of copper in saltwater to several species of macroalgae and microalgae (Table 4b). A comparison of effect levels seen in tests with saltwater plants and the CMC and CCC established to protect saltwater animals indicates that only one test result falls slightly below the CCC. One static unmeasured test, with the microalgae *Scrippsiella faeroense*, provides an 8-day growth EC50 of <1 µg/L (Saifullah 1978). However, this result failed to include a reported background copper concentration of 1.86-4.18 µg/L, placing this response in the range of <2.86–<5.18. In addition, the study included a second experiment with the same species and an 8-day growth EC50 of 5 µg/L; adding in the reported background range brings this EC50 to 6.86–9.18 µg/L. Thus, the animal CCC appears adequate for protecting against chronic seawater plant effects observed in tests included in Table 4b.

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, which is in the range of the saltwater CCC. 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 C, 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.

7.0 BIOACCUMULATION OF COPPER

Because no regulatory action levels for copper and human health are applicable to aquatic organisms, and no consumption limits are established for wildlife, there is no basis for developing a residue-based criterion (or final residue value) for copper based on EPA's current Guidelines.

As more information is acquired about food consumption as a route of copper exposure to fish and macroinvertebrates, bioaccumulation potential—and the link to environmental source concentrations—may become a considerably more important factor in establishing criteria. Currently, the database available for calculating potential bioconcentration (from the water) or bioaccumulation (from all sources) is limited. This is especially true given the current Guidelines requirement for deriving BCFs that all water concentrations be adequately quantitated, and that tissue levels be approaching steady state or else that tests be at least 28 days in duration. Additionally, bioconcentration factors for copper usually are not constant; instead, they generally decrease as aqueous copper concentrations increase (McGeer et al. 2003).

After culling the data according to the Guidelines, the only acceptable bioaccumulation factors for copper (Table 5a, b) were juvenile fathead minnows (464), Asiatic clams (45,300), polychaete worms (1,006–2,950), mussels (2,491–7,730), and Pacific oysters (33,400–57,000).

8.0 OTHER DATA

Many of the data identified for this effort are listed in Appendix C, Other Data, for various reasons, including exposure durations other than 96 hours with the same species reported in Tables 1a and 1b, with some exposures lasting up to 30 days. Acute values for test durations less than 96 hours are available for several species not shown in Tables 1a and 1b. Still, these species have approximately the same sensitivities to copper as species in the same families listed in Tables 1a and 1b. 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 C 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 C, will not be very useful for deriving water quality criteria.

Appendix C also includes tests based on physiological effects, such as changes in growth, appetite, blood parameters, stamina, etc. These were included in Appendix C because they could not be directly interpreted for derivation of criteria.

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 C. 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 C 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 C 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 C to the example criteria presented in this document, it appears that a large proportion of Appendix C 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 I, Unused Data.

9.0 NATIONAL CRITERIA STATEMENT

The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that, except where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not be affected unacceptably if the 4-day average concentration of dissolved copper does not exceed the BLM-derived site-water LC50 (i.e., FAV) divided by the FACR more than once every 3 years on the average (i.e., the CCC) and if the 24-hour average dissolved copper concentration does not exceed the BLM-derived site-LC50 (or FAV) divided by two, more than once every 3 years on the average (i.e., the CMC).

The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that, except where a locally important species is very sensitive, saltwater aquatic organisms and their uses should not be affected unacceptably if the 4-day average concentration of dissolved copper does not exceed 1.9 µg/L more than once every 3 years on the average and if the 24-hour average concentration does not exceed 3.1 µg/L more than once every 3 years on the average.

A return interval of 3 years continues to be EPA's general recommendation. However, the resilience of ecosystems and their ability to recover differ greatly. Therefore, a site-specific return interval for the criteria may be established if adequate justification is provided.

10.0 IMPLEMENTATION

The use of criteria in designing waste treatment facilities requires selection of an appropriate wasteload allocation model. 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 1Q5 or 1Q10 for criterion maximum concentration design flow and 7Q5 or 7Q10 for the criterion continuous concentration design flow in steady-state models for unstressed and stressed systems, respectively. 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-calculated "instantaneous criterion" (i.e., a criterion value appropriate for specific water chemistry conditions at a particular instant) 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 complicate the calculation of site-specific criteria because of their combined effects on variability. EPA is currently in the process of developing guidance on how to address these factors. Presently, EPA expects that few sites have sufficient data for all the input parameters to enable adequate characterization of the inherent variation at a site. Therefore, EPA is currently evaluating probabilistic techniques (Monte Carlo techniques) and statistical analyses to address this issue and anticipates publishing separate BLM implementation guidance.

Table 1a. 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	39.06	50.12	Schubauer-Berigan et al. 1993
Lumbriculus variegatus	adult (mixed age)	S,M,T	N	270	---	LUVA02S	57.44		Schubauer-Berigan et al. 1993
	adult (mixed age)	S,M,T	N	500	---	LUVA03S	56.12		Schubauer-Berigan et al. 1993
Snail,	1.1-2.7 cm	F,M,T	S	2000	---	CADE01F	3661	3027	Arthur and Leonard 1970
Campeloma decisum	1.1-2.7 cm	F,M,T	S	1400	---	CADE02F	2502		Arthur and Leonard 1970
Snail, *Juga plicifera*	adult	F,M,T	C	15	---	JUPL01F	10.84	10.84	Nebeker et al. 1986b
Snail, *Lithoglyphus virens*	adult	F,M,T	C	8	---	LIVI01F	5.75	5.75	Nebeker et al. 1986b
Snail,	0.4-0.7 cm	F,M,T	S	41	---	PHIN01F	19.91	18.60	Arthur and Leonard 1970
Physa integra	0.4-0.7 cm	F,M,T	S	37	---	PHIN02F	17.37		Arthur and Leonard 1970
Freshwater mussel,	juvenile	S,M,T	S	27	---	ACPE01S	10.47	11.35	Keller unpublished
Actinonaias pectorosa	juvenile	S,M,T	S	<29	---	ACPE02S	12.31		Keller unpublished
Freshwater mussel,	1-2 d juv	S,M,T	S	86	---	UTIM01S	170.8	35.97	Keller and Zam 1991
Utterbackia imbecillis	1-2 d juv	S,M,T	S	199	---	UTIM02S	175.3		Keller and Zam 1991
	juvenile	S,M,T	N	76	---	UTIM03S	36.22		Keller unpublished
	juvenile	S,M,T	N	85	---	UTIM04S	38.09		Keller unpublished
	juvenile	S,M,T	N	41	---	UTIM05S	21.54		Keller unpublished
	juvenile	S,M,T	S	79	---	UTIM06S	41.38		Keller unpublished
	juvenile	S,M,T	S	72	---	UTIM07S	35.34		Keller unpublished
	juvenile	S,M,T	S	38	---	UTIM08S	29.87		Keller unpublished
Cladoceran,	<4 h	S,M,T	C	19	---	CEDU01S	9.24	5.75	Carlson et al. 1986
Ceriodaphnia dubia	<4 h	S,M,T	C	17	---	CEDU02S	8.24		Carlson et al. 1986
	<12 h	S,M,D	---	-	25	CEDU03S	7.25		Belanger et al. 1989
	<12 h	S,M,D	---	-	17	CEDU04S	4.71		Belanger et al. 1989
	<12 h	S,M,D	---	-	30	CEDU05S	8.96		Belanger et al. 1989
	<12 h	S,M,D	---	-	24	CEDU06S	6.92		Belanger et al. 1989
	<12 h	S,M,D	---	-	28	CEDU07S	8.26		Belanger et al. 1989
	<12 h	S,M,D	---	-	32	CEDU08S	9.67		Belanger et al. 1989
	<12 h	S,M,D	---	-	23	CEDU09S	6.60		Belanger et al. 1989
	<12 h	S,M,D	---	-	20	CEDU10S	5.64		Belanger et al. 1989
	<12 h	S,M,D	---	-	19	CEDU11S	5.33		Belanger et al. 1989
	<12 h	S,M,D	---	-	26	CEDU12S	2.99		Belanger et al. 1989
	<12 h	S,M,D	---	-	21	CEDU13S	2.36		Belanger et al. 1989
	<12 h	S,M,D	---	-	27	CEDU14S	3.12		Belanger et al. 1989
	<12 h	S,M,D	---	-	37	CEDU15S	4.51		Belanger et al. 1989
	<12 h	S,M,D	---	-	34	CEDU16S	4.07		Belanger et al. 1989
	<12 h	S,M,D	---	-	67	CEDU17S	5.16		Belanger et al. 1989
	<12 h	S,M,D	---	-	38	CEDU18S	2.52		Belanger et al. 1989
	<12 h	S,M,D	---	-	78	CEDU19S	6.35		Belanger et al. 1989
	<12 h	S,M,D	---	-	81	CEDU20S	6.70		Belanger et al. 1989
	<12 h	S,M,D	---	-	28	CEDU21S	3.97		Belanger and Cherry 1990
	<12 h	S,M,D	---	-	84	CEDU22S	10.21		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,T	S	13.4	---	CEDU23S	6.10		Oris et al. 1991
	<24 h	R,M,T,D	S	6.98	5.54	CEDU24R	5.06		Diamond et al. 1997b
Cladoceran,	1 d	S,M,T	C	9.1	---	DAMA01S	2.93	4.98	Nebeker et al. 1986a
Daphnia magna	1 d	S,M,T	C	11.7	---	DAMA02S	3.83		Nebeker et al. 1986a
	<2 h	S,M,T	C	6.6	---	DAMA03S	2.12		Nebeker et al. 1986a
	<2 h	S,M,T	C	9.9	---	DAMA04S	3.25		Nebeker et al. 1986a
	1 d	S,M,T	C	11.7	---	DAMA05S	12.06		Nebeker et al. 1986a
	<4 h	S,M,T	C	6.7	---	DAMA06S	7.26		Nebeker et al. 1986a
	1 d	S,M,T	C	9.1	---	DAMA07S	3.76		Nebeker et al. 1986a
	<2 h	S,M,T	C	5.2	---	DAMA08S	1.80		Nebeker et al. 1986a
	<24 h	S,M,T	S	41.2	---	DAMA09S	22.21		Baird et al. 1991
	<24 h	S,M,T	S	10.5	---	DAMA10S	5.83		Baird et al. 1991
	<24 h	S,M,T	S	20.6	---	DAMA11S	11.68		Baird et al. 1991
	<24 h	S,M,T	S	17.3	---	DAMA12S	9.77		Baird et al. 1991
	<24 h	S,M,T	S	70.7	---	DAMA13S	34.71		Baird et al. 1991
	<24 h	S,M,T	S	31.3	---	DAMA14S	17.37		Baird et al. 1991
	<24 h	S,M,I	S	7.1	---	DAMA15S	2.08		Meador 1991
	<24 h	S,M,I	S	16.4	---	DAMA16S	3.38		Meador 1991
	<24 h	S,M,I	S	39.9	---	DAMA17S	4.16		Meador 1991
	<24 h	S,M,I	S	18.7	---	DAMA18S	2.68		Meador 1991
	<24 h	S,M,I	S	18.9	---	DAMA19S	1.53		Meador 1991
	<24 h	S,M,I	S	39.7	---	DAMA20S	2.38		Meador 1991
	<24 h	S,M,I	S	46	---	DAMA21S	7.37		Meador 1991
	<24 h	S,M,I	S	71.9	---	DAMA22S	8.26		Meador 1991
	<24 h	S,M,I	S	57.2	---	DAMA23S	4.65		Meador 1991
	<24 h	S,M,I	S	67.8	---	DAMA24S	3.30		Meador 1991
	<24 h	S,M,T	C	26	---	DAMA25S	9.24		Chapman et al. Manuscript
	<24 h	S,M,T	C	30	---	DAMA26S	8.09		Chapman et al. Manuscript
	<24 h	S,M,T	C	38	---	DAMA27S	8.84		Chapman et al. Manuscript
	<24 h	S,M,T	C	69	---	DAMA28S	11.12		Chapman et al. Manuscript
	<24 h	S,M,T,D	S	4.8	---	DAMA29S	1.08		Long's MS Thesis
	<24 h	S,M,T,D	S	7.4	---	DAMA30S	15.57		Long's MS Thesis
	<24 h	S,M,T,D	S	6.5	---	DAMA31S	2.17		Long's MS Thesis
Cladoceran,	---	S,M,T	S	11.4	---	DAPC01S	1.37	2.54	Lind et al. Manuscript (1978)
Daphnia pulicaria	---	S,M,T	S	9.06	---	DAPC02S	0.87		Lind et al. Manuscript (1978)
	---	S,M,T	S	7.24	---	DAPC03S	0.74		Lind et al. Manuscript (1978)
	---	S,M,T	S	10.8	---	DAPC04S	0.94		Lind et al. Manuscript (1978)
	---	S,M,T	S	55.4	---	DAPC05S	7.87		Lind et al. Manuscript (1978)
	---	S,M,T	S	55.3	---	DAPC06S	5.33		Lind et al. Manuscript (1978)
	---	S,M,T	S	53.3	---	DAPC07S	3.59		Lind et al. Manuscript (1978)
	---	S,M,T	S	97.2	---	DAPC08S	3.59		Lind et al. Manuscript (1978)
	---	S,M,T	S	199	---	DAPC09S	2.70		Lind et al. Manuscript (1978)
	---	S,M,T	S	213	---	DAPC10S	7.02		Lind et al. Manuscript (1978)

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	---	S,M,T	S	165	---	DAPC11S	5.28		Lind et al. Manuscript (1978)
	---	S,M,T	S	35.5	---	DAPC12S	1.45		Lind et al. Manuscript (1978)
	---	S,M,T	S	78.8	---	DAPC13S	2.29		Lind et al. Manuscript (1978)
	---	S,M,T	S	113	---	DAPC14S	0.98		Lind et al. Manuscript (1978)
	---	S,M,T	S	76.4	---	DAPC15S	1.89		Lind et al. Manuscript (1978)
	---	S,M,T	S	84.7	---	DAPC16S	6.27		Lind et al. Manuscript (1978)
	---	S,M,T	S	184	---	DAPC17S	6.78		Lind et al. Manuscript (1978)
	---	S,M,T	S	9.3	---	DAPC18S	0.93		Lind et al. Manuscript (1978)
	---	S,M,T	S	17.8	---	DAPC19S	1.69		Lind et al. Manuscript (1978)
	---	S,M,T	S	23.7	---	DAPC20S	2.13		Lind et al. Manuscript (1978)
	---	S,M,T	S	27.3	---	DAPC21S	2.17		Lind et al. Manuscript (1978)
	---	S,M,T	S	25.2	---	DAPC22S	3.40		Lind et al. Manuscript (1978)
	---	S,M,T	S	25.1	---	DAPC23S	3.93		Lind et al. Manuscript (1978)
	---	S,M,T	S	25.1	---	DAPC24S	4.66		Lind et al. Manuscript (1978)
Cladoceran, *Scapholeberis sp.*	adult	S,M,T	C	18	---	SCSP01S	8.77	8.77	Carlson et al. 1986
Amphipod, *Gammarus*	1-3 d	F,M,T	S	22	---	GAPS01F	9.31	8.57	Arthur and Leonard 1970
	1-3 d	F,M,T	S	19	---	GAPS02F	7.88		Arthur and Leonard 1970
Amphipod, *Hyalella azteca*	7-14 d	S,M,T	N	17	---	HYAZ01S	12.50	11.36	Schubauer-Berigan et al. 1993
	7-14 d	S,M,T	N	24	---	HYAZ02S	10.24		Schubauer-Berigan et al. 1993
	7-14 d	S,M,T	N	87	---	HYAZ03S	16.20		Schubauer-Berigan et al. 1993
	<7 d	S,M,T	S	24.3	---	HYAZ04S	7.19		Welsh 1996
	<7 d	S,M,T	S	23.8	---	HYAZ05S	7.03		Welsh 1996
	<7 d	S,M,T	S	8.2	---	HYAZ06S	13.79		Welsh 1996
	<7 d	S,M,T	S	10	---	HYAZ07S	16.83		Welsh 1996
Stonefly, *Acroneuria lycorias*	---	S,M,T	S	8300	---	ACLY01S	17484	17484	Warnick and Bell 1969
Midge, *Chironomus decorus*	4th instar	S,M,T	S	739	---	CHDE01S	1925	1925	Kosalwat and Knight 1987
Shovelnose sturgeon, *Scaphirhynchus platorynchus*	fry, 6.01 cm, 0.719 g	S,M,T	S	160	---	SCPL01S	72.50	72.50	Dwyer et al. 1999
Apache trout, *Oncorhynchus apache*	larval, 0.38 g	S,M,T	S	70	---	ONAP01S	33.70	33.70	Dwyer et al. 1995
Lahontan cutthroat trout, *Oncorhynchus clarki henshawi*	larval, 0.34 g	S,M,T	S	80	---	ONCL01S	35.50	31.28	Dwyer et al. 1995
	larval, 0.57 g	S,M,T	S	60	---	ONCL02S	25.55		Dwyer et al. 1995

Table 1a. 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
Cutthroat trout,	7.4 cm, 4.2 g	F,M,T,D	C	398.91	367	ONCL03F	69.79		Chakoumakos et al. 1979
Oncorhynchus clarki	6.9 cm, 3.2 g	F,M,T,D	C	197.87	186	ONCL04F	42.67		Chakoumakos et al. 1979
	8.8 cm, 9.7 g	F,M,T,D	C	41.35	36.8	ONCL05F	19.52		Chakoumakos et al. 1979
	8.1 cm, 4.4 g	F,M,T,D	C	282.93	232	ONCL06F	47.53		Chakoumakos et al. 1979
	6.8 cm, 2.7 g	F,M,T,D	C	186.21	162	ONCL07F	109.1		Chakoumakos et al. 1979
	7.0 cm, 3.2 g	F,M,T,D	C	85.58	73.6	ONCL08F	36.29		Chakoumakos et al. 1979
	8.5 cm, 5.2 g	F,M,T,D	C	116.67	91	ONCL09F	17.19		Chakoumakos et al. 1979
	7.7 cm, 4.4 g	F,M,T,D	C	56.20	44.4	ONCL10F	16.79		Chakoumakos et al. 1979
	8.9 cm, 5.7 g	F,M,T,D	C	21.22	15.7	ONCL11F	9.80		Chakoumakos et al. 1979
Pink salmon,	alevin (newly hatched)	F,M,T	S	143	---	ONGO01F	38.75	37.30	Servizi and Martens 1978
Oncorhynchus gorbuscha	alevin	F,M,T	S	87	---	ONGO02F	18.46		Servizi and Martens 1978
	fry	F,M,T	S	199	---	ONGO03F	72.52		Servizi and Martens 1978
Coho salmon,	6 g	R,M,T,I	---	164	---	ONKI01R	91.75	15.98	Buckley 1983
Oncorhynchus kisutch	parr	F,M,T	C	33	---	ONKI02F	18.70		Chapman 1975
	adult, 2.7 kg	F,M,T	C	46	---	ONKI03F	29.13		Chapman and Stevens 1978
	fry	F,M,T,D,I	---	61	49	ONKI04F	11.42		Mudge et al. 1993
	smolt	F,M,T,D,I	---	63	51	ONKI05F	11.90		Mudge et al. 1993
	fry	F,M,T,D,I	---	86	58	ONKI06F	10.76		Mudge et al. 1993
	parr	F,M,T,D,I	---	103	78	ONKI07F	20.95		Mudge et al. 1993
Rainbow trout,	larval, 0.67 g	S,M,T	S	110	---	ONMY01S	43.37	21.60	Dwyer et al. 1995
Oncorhynchus mykiss	larval, 0.48 g	S,M,T	S	50	---	ONMY02S	26.12		Dwyer et al. 1995
	larval, 0.50 g	S,M,T	S	60	---	ONMY03S	30.49		Dwyer et al. 1995
	swim-up, 0.25 g	R,M,T,D	C	46.7	40	ONMY04R	10.21		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	5.49		Welsh et al. 2000
	swim-up, 0.20-0.24 g	R,M,T,D	C	0	8.1	ONMY07R	10.29		Welsh et al. 2000
	swim-up, 0.20-0.24 g	R,M,T,D	C	0	17.2	ONMY08R	14.63		Welsh et al. 2000
	swim-up, 0.20-0.24 g	R,M,T,D	C	0	32	ONMY09R	20.86		Welsh et al. 2000
	alevin	F,M,T	C	28	---	ONMY10F	18.16		Chapman 1975, 1978
	swim-up, 0.17 g	F,M,T	C	17	---	ONMY11F	11.06		Chapman 1975, 1978
	parr, 8.6 cm, 6.96 g	F,M,T	C	18	---	ONMY12F	8.63		Chapman 1975, 1978
	smolt, 18.8 cm, 68.19	F,M,T	C	29	---	ONMY13F	20.04		Chapman 1975, 1978
	1 g	F,M,T,D	C	-	169	ONMY14F	22.60		Chakoumakos et al. 1979
	4.9 cm	F,M,T,D	C	-	85.3	ONMY15F	9.77		Chakoumakos et al. 1979
	6.0 cm, 2.1 g	F,M,T,D	C	-	83.3	ONMY16F	9.50		Chakoumakos et al. 1979
	6.1 cm, 2.5 g	F,M,T,D	C	-	103	ONMY17F	12.21		Chakoumakos et al. 1979
	2.6 g	F,M,T,D	C	-	274	ONMY18F	42.87		Chakoumakos et al. 1979
	4.3 g	F,M,T,D	C	-	128	ONMY19F	15.91		Chakoumakos et al. 1979
	9.2 cm, 9.4 g	F,M,T,D	C	-	221	ONMY20F	32.16		Chakoumakos et al. 1979
	9.9 cm, 11.5 g	F,M,T,D	C	-	165	ONMY21F	21.91		Chakoumakos et al. 1979
	11.8 cm, 18.7 g	F,M,T,D	C	-	197	ONMY22F	27.61		Chakoumakos et al. 1979
	13.5 cm, 24.9 g	F,M,T,D	C	-	514	ONMY23F	95.34		Chakoumakos et al. 1979
	13.4 cm, 25.6 g	F,M,T,D	C	-	243	ONMY24F	36.51		Chakoumakos et al. 1979

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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
	6.7 cm, 2.65 g	F,M,T	C	2.8	---	ONMY25F	5.83		Cusimano et al. 1986
	parr	F,M,T,D,I	---	90	68	ONMY26F	17.96		Mudge et al. 1993
	swim-up, 0.29 g	F,M,T,D	C	19.6	18	ONMY27F	8.85		Cacela et al. 1996
	swim-up, 0.25 g	F,M,T,D	C	12.9	12	ONMY28F	34.48		Cacela et al. 1996
	swim-up, 0.23 g	F,M,T,D	C	5.9	5.7	ONMY29F	23.48		Cacela et al. 1996
	swim-up, 0.23 g	F,M,T,D	C	37.8	35	ONMY30F	15.35		Cacela et al. 1996
	swim-up, 0.26 g	F,M,T,D	C	25.1	18	ONMY31F	35.69		Cacela et al. 1996
	swim-up, 0.23 g	F,M,T,D	C	17.2	17	ONMY32F	24.39		Cacela et al. 1996
	0.64 g, 4.1 cm	F,M,T,D	C	101	---	ONMY33F	42.35		Hansen et al. 2000
	0.35 g, 3.4 cm	F,M,T,D	C	308	---	ONMY34F	94.18		Hansen et al. 2000
	0.68 g, 4.2 cm	F,M,T,D	C	93	---	ONMY35F	100.8		Hansen et al. 2000
	0.43 g, 3.7 cm	F,M,T,D	C	35.9	---	ONMY36F	52.78		Hansen et al. 2000
	0.29 g, 3.4 cm	F,M,T,D	C	54.4	---	ONMY37F	49.46		Hansen et al. 2000
Sockeye salmon, *Oncorhynchus nerka*	alevin (newly hatched)	F,M,T	S	190	---	ONNE01F	65.95	50.83	Servizi and Martens 1978
	alevin	F,M,T	S	200	---	ONNE02F	73.27		Servizi and Martens 1978
	alevin	F,M,T	S	100	---	ONNE03F	22.28		Servizi and Martens 1978
	alevin	F,M,T	S	110	---	ONNE04F	25.68		Servizi and Martens 1978
	alevin	F,M,T	S	130	---	ONNE05F	33.19		Servizi and Martens 1978
	fry	F,M,T	S	150	---	ONNE06F	42.32		Servizi and Martens 1978
	smolt, 5.5 g	F,M,T	S	210	---	ONNE07F	80.98		Servizi and Martens 1978
	smolt, 5.5 g	F,M,T	S	170	---	ONNE08F	53.26		Servizi and Martens 1978
	smolt, 5.5 g	F,M,T	S	190	---	ONNE09F	65.95		Servizi and Martens 1978
	smolt, 4,8 g	F,M,T	S	240	---	ONNE10F	104.3		Servizi and Martens 1978
Chinook salmon, *Oncorhynchus tshawytscha*	alevin, 0.05 g	F,M,T	C	26	---	ONTS01F	12.84	25.68	Chapman 1975, 1978
	swim-up, 0.23 g	F,M,T	C	19	---	ONTS02F	9.11		Chapman 1975, 1978
	parr, 9.6 cm, 11.58 g	F,M,T	C	38	---	ONTS03F	25.34		Chapman 1975, 1978
	smolt, 14.4 cm, 32.46	F,M,T	C	26	---	ONTS04F	17.95		Chapman 1975, 1978
	3 mo, 1.35 g	F,M,T,I	C	10.2	---	ONTS05F	17.68		Chapman and McCrady 1977
	3 mo, 1.35 g	F,M,T,I	C	24.1	---	ONTS06F	30.37		Chapman and McCrady 1977
	3 mo, 1.35 g	F,M,T,I	C	82.5	---	ONTS07F	33.95		Chapman and McCrady 1977
	3 mo, 1.35 g	F,M,T,I	C	128.4	---	ONTS08F	21.38		Chapman and McCrady 1977
	swim-up, 0.36-0.45 g	F,M,T,D	C	0	7.4	ONTS09F	35.81		Welsh et al. 2000
	swim-up, 0.36-0.45 g	F,M,T,D	C	0	12.5	ONTS10F	28.39		Welsh et al. 2000
	swim-up, 0.36-0.45 g	F,M,T,D	C	0	14.3	ONTS11F	31.17		Welsh et al. 2000
	swim-up, 0.36-0.45 g	F,M,T,D	C	0	18.3	ONTS12F	44.51		Welsh et al. 2000

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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
Bull trout, *Salvelinus confluentus*	0.130 g, 2.6 cm	F,M,T,D	C	228	---	SACO01F	75.20	72.36	Hansen et al. 2000
	0.555 g, 4.0 cm	F,M,T,D	C	207	---	SACO02F	69.33		Hansen et al. 2000
	0.774 g, 4.5 cm	F,M,T,D	C	66.6	---	SACO03F	77.73		Hansen et al. 2000
	1.520 g, 5.6 cm	F,M,T,D	C	50	---	SACO04F	66.12		Hansen et al. 2000
	1.160 g, 5.2 cm	F,M,T,D	C	89	---	SACO05F	74.05		Hansen et al. 2000
Chiselmouth, *Acrocheilus alutaceus*	4.6 cm, 1.25 g	F,M,T	C	143	---	ACAL01F	187.5	187.5	Andros and Garton 1980
Bonytail chub, *Gila elegans*	larval, 0.29 g	S,M,T	S	200	---	GIEL01S	65.62	65.62	Dwyer et al. 1995
Golden shiner, *Notemigonus crysoleucas*	---	F,M,T	C	84600	---	NOCR01F	101999	101999	Hartwell et al. 1989
Fathead minnow, *Pimephales promelas*	adult, 40 mm	S,M,T	S	310	---	PIPR01S	236.3	72.07	Birge et al. 1983
	adult, 40 mm	S,M,T	S	120	---	PIPR02S	95.02		Birge et al. 1983
	adult, 40 mm	S,M,T	S	390	---	PIPR03S	193.6		Birge et al. 1983; Benson & Birge
	---	S,M,T	C	55	---	PIPR04S	34.74		Carlson et al. 1986
	---	S,M,T	C	85	---	PIPR05S	63.41		Carlson et al. 1986
	<24 h	S,M,T	N	15	---	PIPR06S	11.54		Schubauer-Berigan et al. 1993
	<24 h	S,M,T	N	44	---	PIPR07S	18.53		Schubauer-Berigan et al. 1993
	<24 h	S,M,T	N	>200	---	PIPR08S	25.04		Schubauer-Berigan et al. 1993
	<24 h, 0.68 mg	S,M,T	S	4.82	---	PIPR09S	<u>7.75</u>		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	8.2	---	PIPR10S	14.86		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	31.57	---	PIPR11S	22.35		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	21.06	---	PIPR12S	15.66		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	35.97	---	PIPR13S	18.72		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	59.83	---	PIPR14S	14.72		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	4.83	---	PIPR15S	<u>5.06</u>		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	70.28	---	PIPR16S	11.66		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	83.59	---	PIPR17S	<u>6.98</u>		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	182	---	PIPR18S	11.99		Welsh et al. 1993
	larval, 0.32 g	S,M,T	S	290	---	PIPR19S	76.77		Dwyer et al. 1995
	larval, 0.56 g	S,M,T	S	630	---	PIPR20S	165.4		Dwyer et al. 1995
	larval, 0.45 g	S,M,T	S	400	---	PIPR21S	107.6		Dwyer et al. 1995
	larval, 0.39 g	S,M,T	S	390	---	PIPR22S	169.2		Dwyer et al. 1995
	3.2-5.5 cm, 0.42-3.23	S,M,T	S	450	---	PIPR23S	161.2		Richards and Beitinger 1995
	2.8-5.1 cm, 0.30-2.38	S,M,T	S	297	---	PIPR24S	81.18		Richards and Beitinger 1995
	1.9-4.6 cm, 0.13-1.55	S,M,T	S	311	---	PIPR25S	70.03		Richards and Beitinger 1995
	3.0-4.8 cm, 0.23-1.36	S,M,T	S	513	---	PIPR26S	78.68		Richards and Beitinger 1995
	<24 h	S,M,T,D	S	62.23	53.96	PIPR27S	23.42		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	190.5	165.18	PIPR28S	72.39		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	68.58	59.46	PIPR29S	26.01		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	168.91	146.46	PIPR30S	74.50		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	94.62	82.04	PIPR31S	44.23		Erickson et al. 1996a,b

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	<24 h	S,M,T,D	S	143.51	124.43	PIPR32S	91.55		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	120.65	103.76	PIPR33S	76.77		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	196.85	167.32	PIPR34S	100.2		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	133.35	120.02	PIPR35S	114.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	184.15	169.42	PIPR36S	192.6		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	304.8	268.22	PIPR37S	119.2		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	292.1	242.44	PIPR38S	161.1		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	133.35	113.35	PIPR39S	91.76		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	92.71	77.88	PIPR40S	66.17		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	152.4	128.02	PIPR41S	108.5		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	177.8	151.13	PIPR42S	133.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	203.2	166.62	PIPR43S	137.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	190.5	163.83	PIPR44S	125.8		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	196.85	157.48	PIPR45S	148.8		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	234.95	199.71	PIPR46S	161.2		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	146.05	128.52	PIPR47S	109.2		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	171.45	150.88	PIPR48S	129.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	152.4	131.06	PIPR49S	95.81		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	184.15	160.21	PIPR50S	107.2		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	203.2	182.88	PIPR51S	105.7		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	203.2	180.85	PIPR52S	85.58		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	203.2	176.78	PIPR53S	104.4		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	222.25	188.91	PIPR54S	119.3		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	146.05	125.60	PIPR55S	99.21		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	139.7	117.35	PIPR56S	78.65		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	139.7	114.55	PIPR57S	72.30		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	152.4	126.49	PIPR58S	76.77		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	203.2	172.72	PIPR59S	103.1		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	196.85	167.32	PIPR60S	91.87		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	266.7	226.70	PIPR61S	119.7		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	99.06	84.20	PIPR62S	127.2		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	111.13	97.79	PIPR63S	151.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	78.74	70.08	PIPR64S	103.9		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	92.71	81.58	PIPR65S	108.4		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	85.09	77.43	PIPR66S	93.19		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	123.19	110.87	PIPR67S	105.3		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	165.1	151.89	PIPR68S	93.38		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	190.5	175.26	PIPR69S	72.74		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	165.1	145.29	PIPR70S	122.1		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	127	111.76	PIPR71S	88.62		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	92.08	79.18	PIPR72S	52.68		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	66.68	60.01	PIPR73S	34.17		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	393.70	370.08	PIPR74S	156.7		Erickson et al. 1996a,b

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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
	<24 h	S,M,T,D	S	317.50	292.10	PIPR75S	233.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	107.95	101.47	PIPR76S	153.7		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	67.95	62.51	PIPR77S	129.3		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	45.72	42.06	PIPR78S	108.4		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	177.80	172.47	PIPR79S	170.7		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	13.97	12.43	PIPR80S	25.34		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	304.80	271.27	PIPR81S	138.7		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	71.12	71.12	PIPR82S	97.64		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	83.82	79.63	PIPR83S	99.81		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	104.78	99.54	PIPR84S	105.8		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	139.70	132.72	PIPR85S	126.7		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	152.40	137.16	PIPR86S	106.1		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	260.35	182.25	PIPR87S	105.9		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	488.95	268.92	PIPR88S	112.4		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	203.20	188.98	PIPR89S	135.6		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	704.85	662.56	PIPR90S	172.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	952.50	904.88	PIPR91S	183.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	1244.60	995.68	PIPR92S	174.9		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	1485.90	891.54	PIPR93S	126.5		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	781.05	757.62	PIPR94S	170.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	476.25	404.81	PIPR95S	161.2		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	273.05	262.13	PIPR96S	175.3		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	22.23	20.45	PIPR97S	51.55		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	24.13	23.16	PIPR98S	57.82		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	36.83	34.99	PIPR99S	89.18		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	27.94	27.94	PIPR100S	69.87		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	26.67	26.67	PIPR101S	65.31		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	20.32	20.32	PIPR102S	44.85		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	26.67	26.67	PIPR103S	58.92		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	190.50	182.88	PIPR104S	134.8		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	109.86	96.67	PIPR105S	85.13		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	203.20	182.88	PIPR106S	121.76		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	209.55	190.69	PIPR107S	109.6		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	146.05	127.06	PIPR108S	94.04		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	165.10	148.59	PIPR109S	115.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	254.00	223.52	PIPR110S	122.7		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	311.15	283.15	PIPR111S	122.3		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	165.10	150.24	PIPR112S	98.55		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	920.75	644.53	PIPR113S	121.8		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	1073.15	697.55	PIPR114S	112.5		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	1003.30	752.48	PIPR115S	107.9		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	933.45	653.42	PIPR116S	116.9		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	742.95	646.37	PIPR117S	128.2		Erickson et al. 1996a,b

Table 1a. 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	1879.60	939.80	PIPR118S	111.3		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	266.70	253.37	PIPR119S	161.4		Erickson et al. 1996a,b
	---	F,M,T	S	114.00	---	PIPR120F	16.27		Lind et al. Manuscript (1978)
	---	F,M,T	S	121.00	---	PIPR121F	17.88		Lind et al. Manuscript (1978)
	---	F,M,T	S	88.50	---	PIPR122F	11.98		Lind et al. Manuscript (1978)
	---	F,M,T	S	436.00	---	PIPR123F	69.67		Lind et al. Manuscript (1978)
	---	F,M,T	S	516.00	---	PIPR124F	46.18		Lind et al. Manuscript (1978)
	---	F,M,T	S	1586.00	---	PIPR125F	61.17		Lind et al. Manuscript (1978)
	---	F,M,T	S	1129.00	---	PIPR126F	67.41		Lind et al. Manuscript (1978)
	---	F,M,T	S	550.00	---	PIPR127F	41.03		Lind et al. Manuscript (1978)
	---	F,M,T	S	1001.00	---	PIPR128F	31.96		Lind et al. Manuscript (1978)
	30 d, 0.15 g	F,M,T,D	N	96.00	88.32	PIPR129F	35.79		Spehar and Fiandt 1986
	<24 h	F,M,T,D	S	31.75	27.94	PIPR130F	7.72		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	117.48	105.73	PIPR131F	32.23		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	48.26	40.06	PIPR132F	18.97		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	73.03	64.26	PIPR133F	19.48		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	59.06	49.02	PIPR134F	18.47		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	78.74	67.72	PIPR135F	16.80		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	22.23	18.67	PIPR136F	12.29		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	6.99	6.15	PIPR137F	9.83		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	22.23	20.45	PIPR138F	16.03		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	107.32	93.36	PIPR139F	59.69		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	292.10	245.36	PIPR140F	4.33		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	81.28	72.34	PIPR141F	37.18		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	298.45	229.81	PIPR142F	3.79		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	241.30	195.45	PIPR143F	8.56		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	133.35	109.35	PIPR144F	8.64		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	93.98	78.00	PIPR145F	45.63		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	67.95	45.52	PIPR146F	21.06		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	4.76	4.38	PIPR147F	35.59		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	13.97	12.43	PIPR148F	40.38		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	29.85	26.86	PIPR149F	52.53		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	59.69	51.33	PIPR150F	51.59		Erickson et al. 1996a,b
Northern squawfish,	larval, 0.32 g	S,M,T	S	380	---	PTLU01S	92.13	138.2	Dwyer et al. 1995
Ptychocheilus oregonensis	larval, 0.34 g	S,M,T	S	480	---	PTLU02S	207.4		Dwyer et al. 1995

Table 1a. 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	15.23	13.15	Andros and Garton 1980
Ptychocheilus oregonensis	7.2 cm, 3.69 g	F,M,T	C	18	---	PTOR02F	11.36		Andros and Garton 1980
Razorback sucker,	larval, 0.31 g	S,M,T	S	220	---	XYTE01S	66.16	81.75	Dwyer et al. 1995
Xyrauchen texanus	larval, 0.32 g	S,M,T	S	340	---	XYTE02S	101.0		Dwyer et al. 1995
Gila topminnow, *Poeciliposis occidentalis*	2.72 cm, 0.219 g	S,M,T	S	160	---	POAC01S	58.32	58.32	Dwyer et al. 1999
Bluegill,	3.58 cm, 0.63 g	R,M,D	C	-	2200	LEMA01R	2026	1968	Blaylock et al. 1985
Lepomis macrochirus	12 cm, 35 g	F,M,T	S	1100	---	LEMA02F	1965		Benoit 1975
	2.8-6.8 cm	F,M,T	C	1000	---	LEMA03F	3512		Cairns et al. 1981
	3.58 cm, 0.63 g	F,M,D	C	-	1300	LEMA04F	1073		Blaylock et al. 1985
Fantail darter,	3.7 cm	S,M,T	S	330	---	ETFL01S	123.2	130.2	Lydy and Wissing 1988
Etheostoma flabellare	3.7 cm	S,M,T	S	341	---	ETFL02S	126.6		Lydy and Wissing 1988
	3.7 cm	S,M,T	S	373	---	ETFL03S	128.5		Lydy and Wissing 1988
	3.7 cm	S,M,T	S	392	---	ETFL04S	143.1		Lydy and Wissing 1988
Greenthroat darter, *Etheostoma lepidum*	2.26 cm, 0.133 g	S,M,T	S	260	---	ETLE01S	86.34	86.34	Dwyer et al. 1999
Johnny darter,	3.9 cm	S,M,T	S	493	---	ETNI01S	175.5	187.3	Lydy and Wissing 1988
Etheostoma nigrum	3.9 cm	S,M,T	S	483	---	ETNI02S	172.5		Lydy and Wissing 1988
	3.9 cm	S,M,T	S	602	---	ETNI03S	210.4		Lydy and Wissing 1988
	3.9 cm	S,M,T	S	548	---	ETNI04S	193.2		Lydy and Wissing 1988
Fountain darter, *Etheostoma rubrum*	2.02 cm, 0.062 g	S,M,T	S	60	---	ETRU01S	23.38	23.38	Dwyer et al. 1999
Boreal toad, *Bufo boreas*	tadpole, 0.012 g	S,M,T	S	120	---	BUBO01S	49.06	49.06	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	SO4	Cl	HCO3	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	7.50	1.00E+00	5.00E-01	10.00	1.40E+01	1.21E+01	2.63E+01	2.10E+00	1.90E+00	8.14E+01	6.50E+01	3.00E-04

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

Table 1b. Acute Toxicity of Copper to Saltwater Animals

Species[a]	Age, Size, or Lifestage of Test Organism	Test Method[b]	Chemical[c]	Salinity (g/kg)	Reported LC50 or EC50[d] (Total µg/L)	Reported LC50 or EC50[e] (Diss. µg/L)	LC50 or EC50 Used in SMAV Calculations[f] (Diss. µg/L)	SMAV[g] (Diss. µg/L)	Reference
Nematode, *Caenorhabditis elegans*	3-4 d	S, U	S	5.5	260	---	217.9	217.9	Williams & Dusenbery 1990
Polychaete worm, *Phyllodoce maculata*	---	S, U	S	---	120	---	100.6	100.6	McLusky & Phillips 1975
Polychaete worm,	adult	F, M, T	N	31	77	---	69.99	136.9	Pesch & Morgan 1978
Neanthes arenaceodentata	adult	F, M, T	N	31	200	---	181.8		Pesch & Morgan 1978
	---	F, M, T	N	31	222	---	201.8		Pesch & Hoffman 1982
Polychaete worm,	---	S, U	S	---	200	---	167.6	318.3	Jones et al. 1976
Hediste diversicolor	---	S, U	S	---	445	---	372.9		Jones et al. 1976
	---	S, U	S	---	480	---	402.2		Jones et al. 1976
	---	S, U	S	---	410	---	343.6		Jones et al. 1976
	2.0 cm	R, U	N	7.3	357	---	299.2		Ozoh 1992a
	2.0 cm	R, U	N	7.3	357	---	299.2		Ozoh 1992a
	2.0 cm	R, U	N	7.3	247	---	207.0		Ozoh 1992a
	2.0 cm	R, U	N	14.6	307	---	257.3		Ozoh 1992a
	2.0 cm	R, U	N	14.6	400	---	335.2		Ozoh 1992a
	2.0 cm	R, U	N	14.6	462	---	387.2		Ozoh 1992a
	2.0 cm	R, U	N	21.9	375	---	314.3		Ozoh 1992a
	2.0 cm	R, U	N	21.9	362	---	303.4		Ozoh 1992a
	2.0 cm	R, U	N	21.9	480	---	402.2		Ozoh 1992a
	2.0 cm	R, U	N	29.2	512	---	429.1		Ozoh 1992a
	2.0 cm	R, U	N	29.2	360	---	301.7		Ozoh 1992a
	2.0 cm	R, U	N	29.2	500	---	419.0		Ozoh 1992a
	mature	R, U	N	7.6	394	---	NU		Ozoh 1992b
	mature	R, U	N	22.8	949	---	NU		Ozoh 1992b
	mature	R, U	N	30.5	858	---	NU		Ozoh 1992b
	mature	R, U	N	7.6	479	---	NU		Ozoh 1992b
	mature	R, U	N	15.25	628	---	NU		Ozoh 1992b
	mature	R, U	N	22.8	742	---	NU		Ozoh 1992b
	mature	R, U	N	30.5	738	---	NU		Ozoh 1992b
	mature	R, U	N	7.6	360	---	NU		Ozoh 1992b
	mature	R, U	N	15.25	648	---	NU		Ozoh 1992b
	mature	R, U	N	22.8	1,090	---	NU		Ozoh 1992b
	mature	R, U	N	30.5	857	---	NU		Ozoh 1992b
Black abalone, *Haliotis cracherodii*	6.2-17.0 cm	S, U	S	33	50	---	41.90	41.90	Martin et al. 1977
Red abalone,	17.3-20.4 cm	S, U	S	33	65	---	54.47	72.14	Martin et al. 1977
Haliotsis rufescens	48 h larva	S, U	S	30.4	114	---	95.53		Martin et al. 1977

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Mussel,	embryo	S, U	S	---	5.8	---	NU	6.188	Martin et al. 1981
Mytilus spp.	embryo	S, U	S	33	7.21	---	NU		ToxScan 1991a
	embryo	S, U	S	32	6.4	---	NU		ToxScan 1991b
	embryo	S, U	S	32	5.84	---	NU		ToxScan 1991c
	embryo	S, M, D	S	27	---	5.787	5.787		ToxScan 1991a
	embryo	S, M, D	S	28	---	8.889	8.889		ToxScan 1991b
	embryo	S, M, D	S	26	---	6.278	6.278		ToxScan 1991c
	embryo	S, M, D	C	30	---	12.45	12.45		SAIC 1993
	embryo	S, M, D	C	30	---	14.1	14.10		SAIC 1993
	embryo	S, M, D	C	30	---	11.3	11.30		SAIC 1993
	embryo	S, M, D	C	30	---	11.9	11.90		SAIC 1993
	embryo	S, M, T, D	S	28	7.159	5.95	5.950		City of San Jose 1998
	embryo	S, M, T, D	S	28	5.847	5.208	5.208		City of San Jose 1998
	embryo	S, M, T, D	S	28	5.028	5.054	5.054		City of San Jose 1998
	embryo	S, M, T, D	S	28	3.821	3.752	3.752		City of San Jose 1998
	embryo	S, M, T, D	S	28	4.696	3.803	3.803		City of San Jose 1998
	embryo	S, M, T, D	S	28	6.418	4.965	4.965		City of San Jose 1998
	embryo	S, M, T, D	S	28	6.215	5.724	5.724		City of San Jose 1998
	embryo	S, M, T, D	S	28	6.205	5.838	5.838		City of San Jose 1998
	embryo	S, M, T, D	S	28	5.874	5.439	5.439		City of San Jose 1998
	embryo	S, M, T, D	S	28	5.404	4.746	4.746		City of San Jose 1998
	embryo	S, M, T, D	S	28	5.998	5.099	5.099		City of San Jose 1998
	embryo	S, M, T, D	S	28	9.049	8.302	8.302		City of San Jose 1998
	embryo	S, M, T, D	S	28	7.194	5.024	5.024		City of San Jose 1998
	embryo	S, M, T, D	S	28	8.019	6.822	6.822		City of San Jose 1998
	embryo	S, M, T, D	S	28	7.291	5.591	5.591		City of San Jose 1998
	embryo	S, M, T, D	S	28	8.932	6.351	6.351		City of San Jose 1998
	embryo	S, M, T, D	S	28	7.194	5.024	5.024		City of San Jose 1998
	embryo	S, M, T, D	S	28	5.56	4.392	4.392		City of San Jose 1998
	embryo	S, M, T, D	S	28	8.479	7.497	7.497		City of San Jose 1998
	embryo	S, M, T, D	S	28	7.362	6.789	6.789		City of San Jose 1998
	embryo	S, M, T, D	S	28	8.019	6.822	6.822		City of San Jose 1998
	embryo	S, M, T, D	S	28	9.5	7.806	7.806		City of San Jose 1998
Blue mussel,	<4 hr embryo	S,M,T,D	S	20	17.46	17.83	17.830	21.497927	CH2MHill 1999b
Mytilus edulis	<4 hr embryo	S,M,T,D	S	20	22.81	21.35	21.350		CH2MHill 1999b
	<4 hr embryo	S,M,T,D	S	20	27.37	26.1	26.100		CH2MHill 1999b
	1.58 cm	R, U	C	25	122	---	NU		Nelson et al. 1988
Bay scallop, *Argopecten irradians*	2.12 cm	R, U	C	25	29	---	24.30	24.30	Nelson et al. 1988

Table 1b. Acute Toxicity of Copper to Saltwater Animals

Species[a]	Age, Size, or Lifestage of Test Organism	Test Method[b]	Chemical[c]	Salinity (g/kg)	Reported LC50 or EC50[d] (Total µg/L)	Reported LC50 or EC50[e] (Diss. µg/L)	LC50 or EC50 Used in SMAV Calculations[f] (Diss. µg/L)	SMAV[g] (Diss. µg/L)	Reference
Pacific oyster, Crassostrea gigas	embryo	S, M, T	C	30	12.06	---	10.963	10.96254	Harrison et al. 1981
	---	S, U	S	---	5.3	---	NU		Martin et al. 1981
	embryo	S, U	S	33	11.5	---	NU		Coglianese & Martin 1981
	13-17 cm adult	F, M, T	S	33	560	---	NU		Okazaki 1976
Eastern oyster, *Crassostrea virginica*	embryo	S, U	C	26	15.1	---	12.65	14.488	MacInnes & Calabrese 1978
	embryo	S, U	C	26	18.7	---	15.67		MacInnes & Calabrese 1978
	embryo	S, U	C	26	18.3	---	15.34		MacInnes & Calabrese 1978
Common rangia, *Rangia cuneata*	---	S, U	---	5.5	8,000	---	6,704	6,448	Olson & Harrel 1973
	---	S, U	---	22	7,400	---	6,201		Olson & Harrel 1973
Surf clam, *Spisula solidissima*	1.59 cm	R, U	C	25	51	---	42.74	42.74	Nelson et al. 1988
Soft-shell clam, *Mya arenaria*	---	S, U	C	30	39	---	32.68	32.68	Eisler 1977
Coot clam, *Mulina lateralis*	---	S, M, D	C	30	---	21	21.00	17.69	SAIC 1993
	---	S, M, D	C	30	---	19.25	19.25		SAIC 1993
	---	S, M, D	C	30	---	14.93	14.93		SAIC 1993
	---	S, M, D	C	30	---	17.28	17.28		SAIC 1993
	---	S, M, D	C	30	---	16.85	16.85		SAIC 1993
	---	S, M, D	C	30	---	17.44	17.44		SAIC 1993
Squid, *Loligo opalescens*	larva	S, M, T	C	30	309	---	280.9	280.9	Dinnel et al. 1989
Copepod, *Pseudodiaptomus coronatus*	---	S, U	C	30	235.4	---	197.3	197.3	Gentile 1982
Copepod, *Eurytemora affinis*	---	S, U	C	30	928	---	NU	25.83	Gentile 1982
	24 h	R, M, T	---	---	30.6	---	27.82		Sullivan et al. 1983
	24 h	R, M, T	---	---	31.1	---	28.27		Sullivan et al. 1983
	24 h	R, M, T	---	---	28.7	---	26.09		Sullivan et al. 1983
	24 h	R, M, T	---	---	7.5	---	6.818		Sullivan et al. 1983
	24 h	R, M, T	---	---	33.7	---	30.63		Sullivan et al. 1983
	24 h	S, M, D	C	15-16	---	69.4	69.40		Hall et al. 1997
Copepod, *Acartia clausi*	---	S, U	C	30	48.8	---	40.89	40.89	Gentile 1982
Copepod, *Acartia tonsa*	---	S, U	C	10	17	---	14.25	25.74	Sosnowski & Gentile 1978
	---	S, U	C	10	55	---	46.09		Sosnowski & Gentile 1978
	---	S, U	C	30	31	---	25.98		Sosnowski & Gentile 1978
Copepod, *Tigriopus californicus*	egg	R, U	N	35	229	---	191.9	196.2	O'Brien et al. 1988
	1st nauplius	R, U	N	35	76	---	63.69		O'Brien et al. 1988
	2nd nauplius	R, U	N	35	19	---	15.92		O'Brien et al. 1988
	3rd nauplius	R, U	N	35	159	---	133.2		O'Brien et al. 1988
	4th nauplius	R, U	N	35	184	---	154.2		O'Brien et al. 1988

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Table 1b. Acute Toxicity of Copper to Saltwater Animals

Species[a]	Age, Size, or Lifestage of Test Organism	Test Method[b]	Chemical[c]	Salinity (g/kg)	Reported LC50 or EC50[d] (Total µg/L)	Reported LC50 or EC50[e] (Diss. µg/L)	LC50 or EC50 Used in SMAV Calculations[f] (Diss. µg/L)	SMAV[g] (Diss. µg/L)	Reference
	5th nauplius	R, U	N	35	261	---	218.7		O'Brien et al. 1988
	6th nauplius	R, U	N	35	305	---	255.6		O'Brien et al. 1988
	1st copepodite	R, U	N	35	375	---	314.3		O'Brien et al. 1988
	2nd copepodite	R, U	N	35	496	---	415.6		O'Brien et al. 1988
	3rd copepodite	R, U	N	35	413	---	346.1		O'Brien et al. 1988
	4th copepodite	R, U	N	35	394	---	330.2		O'Brien et al. 1988
	5th copepodite	R, U	N	35	394	---	330.2		O'Brien et al. 1988
	6th copepodite	R, U	N	35	762	---	638.6		O'Brien et al. 1988
Copepod, *Tigriopus furcata*	<24 h	R, M, D	S	---	---	178	178.0	178.0	Bechmann 1994
Mysid, *Holmesimysis costata*	3 d	S, M, T	C	35-38	17	---	15.45	15.45	Martin et al. 1989
Mysid, *Americamysis bahia*	24 h	R, U	C	25	153	---	NU	164.529	Cripe 1994
	24 h	F, M, T	N	30	181	---	164.5		Lussier et al. 1985; Gentile 1982
Mysid, Americamysis *bigelowi*	24 h	F, M, T	N	30	141	---	128.2	128.2	Gentile 1982
Mysid, *Neomysis mercedis*	<5 d	F, M, T	S	2	71	---	64.54	123.4	Brandt et al. 1993
	>15 d	F, M, T	S	2	220	---	200.0		Brandt et al. 1993
	>15 d	F, M, T	S	2	160	---	145.4		Brandt et al. 1993
Amphipod, *Corophium insidiosum*	0.8-1.2 cm	S, U	C	---	600	---	502.8	502.8	Reish 1993
Amphipod, *Elasmopus bampo*	0.8-1.2 cm	S, U	C	---	250	---	209.5	209.5	Reish 1993
Sand shrimp, *Crangon spp.*	6.1 cm adult	F, M, T	C	30.1	898	---	816.3	816.3	Dinnel et al. 1989
American lobster, *Homarus americanus*	24 h larva	S, U	N	30.5	48	---	40.22	40.22	Johnson & Gentile 1979
Dungeness crab, *Cancer magister*	larva	S, U	S	---	49	---	41.06	41.06	Martin et al. 1981
	zooea	S, M, T	C	30	96	---	NU		Dinnel et al. 1989
Green crab, *Carcinus maenas*	larva	S, U	S	---	600	---	502.8	502.8	Connor 1972
Sea urchin, *Arbacia punctulata*	embryo	S,M,D	C	30	---	21.4	21.4	21.4	SAIC 1993
Sea urchin, *Strongylocentrotus purpuratus*	embryo	S, M, T	S	28	13.4	---	12.18	12.81	City of San Jose 1998
		S, M, T, D	S	28	14.383	13.515	13.52		City of San Jose 1998
		S, M, T, D	S	28	15.048	12.765	12.77		City of San Jose 1998
Coho salmon, *Oncorhynchus kisutch*	smolt	F, M, T	C	28.6	601	---	546.3	546.3	Dinnel et al. 1989
Mangrove rivulus, *Rivulus marmoratus*	4-6 wks	F, M, D	S	14	---	1,250	1,250	1,419	Lin & Dunson 1993
	4-6 wks	F, M, D	S	14	---	1610	1,610		Lin & Dunson 1993

Table 1b. Acute Toxicity of Copper to Saltwater Animals

Species[a]	Age, Size, or Lifestage of Test Organism	Test Method[b]	Chemical[c]	Salinity (g/kg)	Reported LC50 or EC50[d] (Total µg/L)	Reported LC50 or EC50[e] (Diss. µg/L)	LC50 or EC50 Used in SMAV Calculations[f] (Diss. µg/L)	SMAV[g] (Diss. µg/L)	Reference
Sheepshead minnow, *Cyprinodon variegatus*	---	R, M, T	C or S	30	368	---	334.5	334.5	Hughes et al. 1989
Killifish, *Fundulus heteroclitus*	---	S, U	C	5.5	3,100	---	NU	1,690	Dorfman 1977
	---	S, U	C	23.6	2,000	---	NU		Dorfman 1977
	---	S, U	C	6.1	2,300	---	NU		Dorfman 1977
	---	S, U	C	24	400	---	NU		Dorfman 1977
	4-6 wks	F, M, D	S	14	---	1,690	1,690		Lin & Dunson 1993
Topsmelt, *Atherinops affinis*	8 d larva	S, M, T	C	33	288	---	261.8	220.9	Anderson et al. 1991
	8 d larva	S, M, T	C	33	212	---	192.7		Anderson et al. 1991
	8 d larva	S, M, T	C	33	235	---	213.6		Anderson et al. 1991
Inland silverside, *Menidia beryllina*	---	S, M, D	S	---	---	115.4	115.4	111.1	ToxScan 1991a
	---	S, M, D	S	---	---	96.5	96.50		ToxScan 1991b
	---	S, M, D	S	---	---	123	123.0		ToxScan 1991c
Atlantic silverside, *Menidia menidia*	3 wk larva	F, M, T	N	31	66.6	---	60.54	123.3	Cardin 1982
	1 wk larva	F, M, T	N	30.4	216.5	---	196.8		Cardin 1982
	1 d larva	F, M, T	N	30.4	101.8	---	92.54		Cardin 1982
	3 d larva	F, M, T	N	31	97.6	---	88.72		Cardin 1982
	2 wk larva	F, M, T	N	30	155.9	---	141.7		Cardin 1982
	1 d larva	F, M, T	N	30	197.6	---	179.6		Cardin 1982
	juvenile	F, M, T	N	30	190.9	---	173.5		Cardin 1982
Tidewater silverside, *Menidia peninsulae*	19 d larva	S, U	N	20	140	---	117.3	117.3	Hansen 1983
Striped bass, *Morone saxatilis*	1-2 mo	S, U	S	5	2,680	---	2,246	4648.0	Reardon & Harrell 1990
	1-2 mo	S, U	S	10	8,080	---	6,771		Reardon & Harrell 1990
	1-2 mo	S, U	S	15	7,880	---	6,603		Reardon & Harrell 1990
Florida pompano, *Trachinotus carolinus*	---	S, U	S	10	360	---	301.7	345.0	Birdsong & Avavit 1971
	---	S, U	S	20	380	---	318.4		Birdsong & Avavit 1971
	---	S, U	S	30	510	---	427.4		Birdsong & Avavit 1971
Sheepshead, *Archosargus probatocephalus*	18-21 cm	S, U	C	30	1,140	---	955.3	955.3	Steele 1983a
Pinfish, *Langodon rhomboides*	13-17 cm	S, U	C	30	2,750	---	2,305	2,305	Steele 1983a
Spot, *Leiostomus xanthurus*	adult	S, U	N	20	280	---	234.6	234.6	Hansen 1983
Atlantic croaker, *Micropogon undulatus*	16-19 cm	S, U	C	30	5,660	---	4,743	4,743	Steele 1983a
Cabezon, *Scorpaenichthys*	larva	S, M, T	C	27	95	---	86.36	86.36	Dinnel et al. 1989
Shiner perch, *Cymatogaster aggregata*	9.7 cm adult	F, M, T	C	29.5	418	---	380.0	380.0	Dinnel et al. 1989

Table 1b. Acute Toxicity of Copper to Saltwater Animals

Species[a]	Age, Size, or Lifestage of Test Organism	Test Method[b]	Chemical[c]	Salinity (g/kg)	Reported LC50 or EC50[d] (Total µg/L)	Reported LC50 or EC50[e] (Diss. µg/L)	LC50 or EC50 Used in SMAV Calculations[f] (Diss. µg/L)	SMAV[g] (Diss. µg/L)	Reference
Summer flounder, *Paralichthys dentatus*	46 d, 1.8-2.2 cm, 0.03-0.05 g	S,M,T,D	S	22	610	586	NU	12.66	CH2MHill 1999a
	48 d, 2.0-2.4 cm, 0.04-0.08 g	S,M,T,D	S	22	1,029	928	NU		CH2MHill 1999a
	57 d, 2.4-2.8 cm, 0.07-0.12 g	S,M,T,D	S	22	606	597	NU		CH2MHill 1999a
	early cleavage embryo	F, M, T	N	30	16.3	---	14.82		Cardin 1982
	early cleavage embryo	F, M, T	N	30	11.9	---	10.82		Cardin 1982
	blastula stage embryo	F, M, T	N	30	111.8	---	NU		Cardin 1982
	blastula stage embryo	F, M, T	N	30	77.5	---	NU		Cardin 1982
Winter flounder, *Pseudopleuronectes americar*	blastula	F, M, T	N	30	167.3	---	152.1	124.9	Cardin 1982
	pre-cleavage zygote	F, M, T	N	30	52.7	---	47.90		Cardin 1982
	blastula	F, M, T	N	28	158	---	143.6		Cardin 1982
	blastula	F, M, T	N	30	173.7	---	157.9		Cardin 1982
	pre-cleavage zygote	F, M, T	N	28	271	---	246.3		Cardin 1982
	pre-cleavage zygote	F, M, T	N	30	132.8	---	120.7		Cardin 1982
	blastula	F, M, T	N	30	148.2	---	134.7		Cardin 1982
	early cleavage embryo	F, M, T	N	30	98.2	---	89.26		Cardin 1982

[a]Species appear in order taxonomically, with invertebrates listed first and fish 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 as reported by the author.
[f]If author did not report a dissolved copper LC50 value, then a conversion factor (CF) was applied to the total copper LC50 to estimate dissolved copper values. For tests in which copper was not measured, the total copper LC50 was multiplied by a CF of 0.838, and for tests in which copper concentrations were measured, the total copper LC50 was multiplied by a CF of 0.909 see discussion in Section 4 and Appendix E). 'NU' indicates that a test result was not used in the SMAV calculation, typically because data for a more sensitive life stage were used preferentially.
[g]The species mean acute value (SMAV) is calculated as the geometric mean of the tabulated LC50 or EC50 values for each species (Stephan et al. 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
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,	179	28.42[b]	7.90	3.60	Belanger et al. 1989		
Ceriodaphnia dubia	94.1	63.33[b]	19.36	3.27	Belanger et al. 1989		
	57	13.4	24.5	0.55	Oris et al. 1991		
	--	18.974[c]	9.17	2.07	Carlson et al. 1986	2.90[h]	✓
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[e]	2.83	9.10	Winner 1985		
Daphnia pulex	115	27.6[e]	7.07	3.90	Winner 1985		
	230	28.79[e]	9.16	3.14	Winner 1985	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[f]	18	12.88	Horning and Neiheisel 1979	12.88	
Fathead minnow, *Pimephales promelas*	45	106.875[g]	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 from Winner (1985) in Table 1.

[f]Geometric mean of three values from Horning and Neiheisel (1979) in Appendix D.

[g]Geometric mean of three values from Lind et al. (1978) in Table 1.

[h]ACR from Oris et al. (1991) not used in calculating overall ratio for species because it is <1.

FACR
Freshwater final acute-chronic ratio = 3.23
Saltwater final acute-chronic ratio = 3.23

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

Rank	GMAV	Species	SMAV (µg/L)	ACR
27	101,999	Golden shiner, *Notemigonus crysoleucas*	101,999	
26	17,484	Stonefly, *Acroneuria lycorias*	17,484	
25	3,027	Snail, *Campeloma decisum*	3,027	171.19
24	1,968	Bluegill sunfish, *Lepomis macrochirus*	1,968	40.49
23	1,925	Midge, *Chironomus decorus*	1,925	
22	187.5	Chiselmouth, *Acrocheilus alutaceus*	187.5	
21	83.76	Fantail darter, *Etheostoma flabellare*	130.2	
		Greenthroat darter, *Etheostoma lepidum*	86.34	
		Johnny darter, *Etheostoma nigrum*	187.3	
		Fountain darter, *Etheostoma rubrum*	23.38	
20	81.75	Razorback sucker, *Xyrauchen texanus*	81.75	
19	72.50	Shovelnose sturgeon, *Scaphirhynchus platorynchus*	72.50	
18	72.36	Bull trout, *Salvelinus confluentus*	72.36	
17	72.07	Fathead minnow, *Pimephales promelas*	72.07	11.40
16	65.62	Bonytail chub, *Gila elegans*	65.62	
15	58.32	Gila topminnow, *Poeciliposis occidentalis*	58.32	
14	50.12	Worm, *Lumbriculus variegatus*	50.12	
13	49.06	Boreal toad, *Bufo boreas*	49.06	
12	42.64	Colorado squawfish, *Ptychocheilus lucius*	138.2	
		Northern squawfish, *Ptychocheilus oregonensis*	13.15	
11	35.97	Freshwater mussel, *Utterbackia imbecillis*	35.97	
10	29.11	Apache trout, *Oncorhynchus apache*	33.70	
		Cutthroat trout, *Oncorhynchus clarki*	31.28	
		Pink salmon, *Oncorhynchus gorbuscha*	37.30	
		Coho salmon, *Oncorhynchus kisutch*	15.98	
		Rainbow trout, *Oncorhynchus mykiss*	21.60	2.88
		Sockeye salmon, *Oncorhynchus nerka*	50.83	
		Chinook salmon, *Oncorhynchus tshawytscha*	25.68	5.59
9	18.60	Snail, *Physa integra*	18.60	
8	11.36	Amphipod, *Hyalella azteca*	11.36	
7	11.35	Freshwater mussel, *Actinonaias pectorosa*	11.35	
6	10.84	Snail, *Juga plicifera*	10.84	
5	8.77	Cladoceran, *Scapholeberis sp.*	8.77	
4	8.57	Amphipod, *Gammarus pseudolimnaeus*	8.57	
3	5.75	Cladoceran, *Ceriodaphnia dubia*	5.75	2.90
2	5.75	Snail, *Lithoglyphus virens*	5.75	
1	3.56	Cladoceran, *Daphnia magna*	4.98	3.42
		Cladoceran, *Daphnia pulicaria*	2.54	

Table 3b. Ranked Saltwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios

GMAV Rank	GMAV (µg/L)	Species	SMAV (µg/L)	ACR
44	6,448	Common rangia, *Rangia cuneata*	6,448	
43	4,743	Atlantic croaker, *Micropogon undulatus*	4,743	
42	4,648	Striped bass, *Morone saxatilis*	4,648	
41	2,305	Pinfish, *Langodon rhomboides*	2,305	
40	1,690	Killifish, *Fundulus heteroclitus*	1,690	
39	1,419	Mangrove rivulus, *Rivulus marmoratus*	1,419	
38	955.3	Sheepshead, *Archosargus probatocephalus*	955.3	
37	816.3	Sand shrimp, *Crangon spp.*	816.3	
36	546.3	Coho salmon, *Oncorhynchus kisutch*	546.3	
35	502.8	Green crab, *Carcinus maenas*	502.8	
34	502.8	Amphipod, *Corophium insidiosum*	502.8	
33	380.0	Shiner perch, *Cymatogaster aggregata*	380.0	
32	345.0	Florida pompano, *Trachinotus carolinus*	345.0	
31	334.5	Sheepshead minnow, *Cyprinodon variegatus*	334.5	1.48
30	318.3	Polychaete worm, *Hediste diversicolor*	318.3	
29	280.9	Squid, *Loligo opalescens*	280.9	
28	234.6	Spot, *Leiostomus xanthurus*	234.6	
27	220.9	Topsmelt, *Atherinops affinis*	220.9	
26	217.9	Nematode, *Caenorhabditis elegans*	217.9	
25	209.5	Amphipod, *Elasmopus bampo*	209.5	
24	197.3	Copepod, *Pseudodiaptomus coronatus*	197.3	
23	186.9	Copepod, *Tigriopus furcata*	178.0	
		Copepod, *Tigriopus californicus*	196.2	
22	145.2	Mysid, *Americamysis bahia*	164.5	
		Mysid, Mysidopsis bigelowi	128.2	
21	136.9	Polychaete worm, Neanthes arenaceodentata	136.9	
20	124.9	Winter flounder, *Pseudopleuronectes americanus*	124.9	
19	123.4	Mysid, *Neomysis mercedis*	123.4	
18	117.1	Tidewater silverside, *Menidia peninsulae*	117.3	
		Atlantic silverside, *Menidia menidia*	123.3	
		Inland silverside, *Menidia beryllina*	111.1	
17	100.6	Polychaete worm, *Phyllodoce maculata*	100.6	
16	86.4	Cabezon, *Scorpaenichthys marmoratus*	86.36	
15	54.98	Black abalone, *Haliotis cracherodii*	41.90	
		Red abalone, *Haliotsis rufescens*	72.14	
14	42.74	Surf clam, *Spisula solidissima*	42.74	
13	41.06	Dungeness crab, *Cancer magister*	41.06	
12	40.22	American lobster, *Homarus americanus*	40.22	
11	32.68	Soft-shell clam, *Mya arenaria*	32.68	
10	32.45	Copepod, *Acartia tonsa*	25.74	

Table 3b. Ranked Saltwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios

GMAV Rank	GMAV (µg/L)	Species	SMAV (µg/L)	ACR
		Copepod, *Acartia clausi*	40.89	
9	25.83	Copepod, *Eurytemora affinis*	25.83	
8	24.30	Bay scallop, *Argopecten irradians*	24.30	
7	21.40	Sea urchin, *Arbacia punctulata*	21.40	
6	17.69	Coot clam, *Mulina lateralis*	17.69	
5	15.45	Mysid, *Holmesimysis costata*	15.45	
4	12.81	Sea urchin, *Strongylocentrotus purpuratus*	12.81	
3	12.66	Summer flounder, *Paralichthys dentatus*	12.66	
2	12.60	Eastern oyster, *Crassostrea virginica*	14.49	
		Pacific oyster, *Crassostrea gigas*	10.96	
1	11.53	Blue mussel, *Mytilus edulis*	21.50	
		Mussel, *Mytilus sp*.	6.19	

Table 3c. Freshwater and Saltwater 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	$(\ln GMAV)^2$	P = R/(n+1)	SQRT(P)
4	8.5666	2.148	4.613	0.14286	0.3780
3	5.7536	1.750	3.062	0.10714	0.3273
2	5.7472	1.749	3.058	0.07143	0.2673
1	3.5579	1.269	1.611	0.03571	0.1890
Sum:		**6.916**	**12.34**	**0.3571**	**1.1615**

S =	4.419
L =	0.4456
A =	1.434
Calculated FAV =	**4.194590**
Calculated CMC =	**2.097**

Dissolved Copper Criterion Maximum Concentration (CMC) = 2.1 µg/L (for example normalization chemistry see Table 1a, footnote f)
Criteria Lethal Accumulation (LA50) based on example normalization chemistry = 0.0412 nmol/g wet wt
Criterion Continuous Concentration (CCC) = 4.19459/3.23 = 1.3 µg/L (for example normalization chemistry see Table 1a, footnote f)

Calculated Saltwater FAV based on 4 lowest values: Total Number of GMAVs in Data Set = 44

Rank	GMAV	lnGMAV	$(\ln GMAV)^2$	P = R/(n+1)	SQRT(P)
4	12.81	2.550	6.503	0.08889	0.2981
3	12.66	2.538	6.444	0.06667	0.2582
2	12.60	2.534	6.421	0.04444	0.2108
1	11.53	2.445	5.979	0.02222	0.1491
Sum:		**10.068**	**25.35**	**0.2222**	**0.9162**

S =	0.752		
L =	2.3447		
A =	2.513		
Calculated FAV =	**12.340**	**Lowered FAV =**	**6.188**
Calculated CMC =	**6.170**	**Calculated CMC =**	**3.094**

Dissolved Copper Final Acute Value (FAV) = 6.188 µg/L (lowered from 12.30 to protect *Mytilus sp.*)
Dissolved Copper Criterion Maximum Concentration (CMC) = 6.188/2 = 3.1 µg/L
Criterion Continuous Concentration (CCC) = 6.188/3.23 = 1.9 µg/L

S = Scale parameter or slope
L = Location parameter or intercept
P = Cumulative probability
A = lnFAV

Table 4a. 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 4a. 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 4a. 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.

Table 4b. Toxicity of Copper to Saltwater Plants

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result[b] (total µg/L)	Reference
Dinoflagellate, *Amphidinium carteri*	S,U	Copper chloride	21	14 days	83% reduction in growth	<50	Erickson et al. 1970
Dinoflagellate, *Gymnodinium splendens*	S,U	Copper sulfate	31.6-33.3	5 days	EC50 (growth)	20	Saifullah 1978
Dinoflagellate, *Prorocentrum micans*	S,U	Copper sulfate	31.6-33.3	8 days	EC50 (growth)	5	Saifullah 1978
Dinoflagellate, *Scrippsiella faeroense*	S,U	Copper sulfate	31.6-33.3	5 days	EC50 (growth)	5	Saifullah 1978
Dinoflagellate, *Scrippsiella faeroense*	R,U	Copper sulfate	31.6-33.3	8 days	EC50 (growth)	<1	Saifullah 1978
Dinoflagellate, *Simbiodinium microadriaticum*	S,M,T	Copper sulfate	FSW	23 days	46% reduction in growth (significant)	40	Goh and Chou 1997
Dinoflagellate, *Simbiodinium microadriaticum*	S,M,T	Copper sulfate	FSW	23 days	26% reduction in growth (not significant)	42	Goh and Chou 1997
Green alga, *Chlorella stigmatophora*	S,M,T	Copper chloride	35	21 days	EC50 (cell volume)	70	Christensen et al. 1979
Green alga (zoospores), *Enteromorpha intestinalis*	S,U	-	-	5 days	EC50 (development to 2+ cell stage)	10	Fletcher 1989
Green alga, *Olisthodiscus luteus*	S,U	Copper chloride	21	14 days	74% reduction in growth	<50	Erickson et al. 1970
Diatom, *Nitzschia closterium*	-	-	-	96 hr	EC50 (growth)	33	Rosko and Rachlin 1975
Diatom, *Nitzschia thermalis*	S,U	Copper sulfate	35.7	Several days	No growth	38.1	Metaxas and Lewis 1991
Diatom, *Skeletonema costatum*	S,U	Copper chloride	21	14 days	58% reduction in growth	50	Erickson et al. 1970
Diatom, *Skeletonema costatum*	S,U	Copper sulfate	35.7	Several days	LOEC (no growth)	31.8	Metaxas and Lewis 1991
Diatom, *Skeletonema costatum*	S,U	Copper chloride	-	96 hr	EC50 (growth)	45	Nassiri et al. 1997
Diatom, *Thalassiosira aestevallis*	S,U	Copper chloride	-	3-4 days	Reduced growth	19	Hollibaugh et al. 1980
Red alga (tetrasporophyte), *Champia parvula*	R,M,T	Copper chloride	30	11 days	Reduced growth	4.6	Steele and Thursby 1983
Red alga (tetrasporophyte), *Champia parvula*	R,M,T	Copper chloride	30	11 days	Reduced production	13.3	Steele and Thursby 1983
Red alga (mature), *Champia parvula*	R,M,T	Copper chloride	30	7 days	Reduced female growth	4.7	Steele and Thursby 1983
Red alga (mature), *Champia parvula*	R,M,T	Copper chloride	30	7 days	Stopped sexual reproduction	7.3	Steele and Thursby 1983

Table 4b. Toxicity of Copper to Saltwater Plants

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result[b] (total µg/L)	Reference
Kelp (meiospore), *Laminaria saccharina*	R,U	Copper sulfate	-	21 days	Reduced gametophyte development rate	5	Chung and Brinkhuis 1986
Kelp (1-3 cm sporophyte), *Laminaria saccharina*	S,U	Copper sulfate	-	9 days	LOEC (100% mortality)	100	Chung and Brinkhuis 1986
Kelp (8-10 cm sporophyte), *Laminaria saccharina*	S,U	Copper sulfate	-	-	23% decrease in blade growth	10	Chung and Brinkhuis 1986
Giant kelp, *Macrocystis pyrifera*	S,U	-	SW	96-hr	EC50 (photosynthesis)	60	Clendenning and North 1959
Giant kelp, *Macrocystis pyrifera*	R,M,T	Copper chloride	33	19-20 days	NOEC (sporophyte production)	<10.2	Anderson et al. 1990
Giant kelp, *Macrocystis pyrifera*	R,M,T	Copper chloride	33	19-20 days	NOEC (sporophyte production)	10.2	Anderson et al. 1990

[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.

Table 5a. Bioaccumulation of Copper by Freshwater Organisms

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Concentration in Water[a] (µg/L)	Duration Days	Tissue	BCF or BAF	Reference
Asiatic clam, *Corbicula fluminea*	Copper sulfate	-	16	28 days	Soft tissue	45,300[b]	Graney et al. 1983
Macroinvertebrates	Field study	-	3	-	Whole body	1,533	Farag et al. 1998
Macroinvertebrates	Field study	-	3	-	Whole body	4,800	Farag et al. 1998
Macroinvertebrates	Field study	-	3	-	Whole body	2,267	Farag et al. 1998
Macroinvertebrates	Field study	-	1	-	Whole body	5,600	Farag et al. 1998
Macroinvertebrates	Field study	-	5	-	Whole body	2,000	Farag et al. 1998
Fathead minnow (larva), *Pimephales promelas*	-	45	5	30	Whole body	464	Lind et al. manuscript
Yellow perch, *Perca flavescens*	Field study	-	1	-	Whole body	9,600	Farag et al. 1998
Yellow perch, *Perca flavescens*	Field study	-	5	-	Whole body	1,860	Farag et al. 1998

[a] Results are based on copper, not the chemical.

[b] Recalculated; authors substracted control residues.

Table 5b. Bioaccumulation of Copper by Saltwater Organisms

Species	Chemical	Concentration in Water (µg/L)	Salinity (g/kg)	Duration Days	Tissue	BCF or BAF	Reference
Polychaete worm, *Phyllodoce maculata*	Copper sulfate	40	FSWb	35	Whole body	2,500	McLusky and Phillips 1975
Polychaete worm, *Neanthes arenaceodentata*	Copper nitrate	40	31	28	Whole body	2,950	Pesch and Morgan 1978
Polychaete worm, *Eudistylia vancouveri*	Copper chloride	6	30.4	29	Body (less radioles)	1,006	Young et al. 1979
Blue mussel (0.45 cm), *Mytilus edulis*	Copper chloride	3	25	550	Soft tissue	7,730	Calabrese et al. 1984
Blue mussel (0.45 cm), *Mytilus edulis*	Copper chloride	7.9	25	550	Soft tissue	4,420	Calabrese et al. 1984
Blue mussel (0.45 cm), *Mytilus edulis*	Copper chloride	12.7	25	550	Soft tissue	5,320	Calabrese et al. 1984
Mussel (6.02-6.34 cm), *Mytillus galloprovincialis*	Field study	0.285	37-38	266	Soft tissue	3,263	Martincic et al. 1992
Mussel (6.02-6.34 cm), *Mytillus galloprovincialis*	Field study	0.446	37-38	266	Soft tissue	2,491	Martincic et al. 1992
Mussel (6.02-6.34 cm), *Mytillus galloprovincialis*	Field study	0.203	37-38	266	Soft tissue	4,384	Martincic et al. 1992
Mussel (6.02-6.34 cm), *Mytillus galloprovincialis*	Field study	0.177	37-38	266	Soft tissue	4,915	Martincic et al. 1992
Bay scallop (5.12-6.26 cm), *Argopecten irradians*	Copper chloride	4.56	29-32	56	Muscle	185	Zaroogian and Johnson 1983
Bay scallop (5.12-6.26 cm), *Argopecten irradians*	Copper chloride	4.56	29-32	56	Viscera	3,816	Zaroogian and Johnson 1983
Pacific oyster, *Crassostrea gigas*	Field study	25.45	-	32	Soft tissue	34,600	Han and Hung 1990
Pacific oyster, *Crassostrea gigas*	Field study	9.66	-	32	Soft tissue	57,000	Han and Hung 1990
Pacific oyster, *Crassostrea gigas*	Field study	10.37	-	32	Soft tissue	33,400	Han and Hung 1990
Atlantic oyster, *Crassostrea virginica*	Field study	25	31	140	Soft tissue	27,800	Shuster and Pringle 1968
Soft-shell clam, *Mya arenaria*	Field study	100	31	35	Soft tissue	790	Shuster and Pringle 1968

[a] Results are based on copper, not the chemical.

[b] FSW=Full Strength Seawater.

Table 6. Species Numbers Used in Figure 4

Species #	Species	N
1	Worm, *Lumbriculus variegatus*	3
2	Snail, *Campeloma decisum*	2
3	Snail, *Juga plicifera*	1
4	Snail, *Lithoglyphus virens*	1
5	Snail, *Physa integra*	2
6	Freshwater mussel, *Actinonaias pectorosa*	2
7	Freshwater mussel, *Utterbackia imbecillis*	8
8	Cladoceran, *Ceriodaphnia dubia*	24
9	Cladoceran, *Daphnia magna*	31
10	Cladoceran, *Daphnia pulicaria*	24
11	Cladoceran, *Scapholeberis sp.*	1
12	Amphipod, *Gammarus pseudolimnaeus*	2
13	Amphipod, *Hyallela azteca*	7
14	Stonefly, *Acroneuria lycorias*	1
15	Midge, *Chironomus decorus*	1
16	Shovelnose sturgeon, *Scaphirhynchus platorynchus*	1
17	Apache trout, *Oncorhynchus apache*	1
18	Cutthroat trout, *Oncorhynchus clarki*	11
19	Pink salmon, *Oncorhynchus gorbuscha*	3
20	Coho salmon, *Oncorhynchus kisutch*	7
21	Rainbow trout, *Oncorhynchus mykiss*	37
22	Sockeye salmon, *Oncorhynchus nerka*	10
23	Chinook salmon, *Oncorhynchus tshawytscha*	12
24	Bull trout, *Salvelinus confluentus*	5
25	Chiselmouth, *Acrocheilus alutaceus*	1
26	Bonytail chub, *Gila elegans*	1
27	Golden shiner, *Notemigonus crysoleucas*	1
28	Fathead minnow, *Pimephales promelas*	150
29	Colorado squawfish, *Ptychocheilus lucius*	2
30	Northern squawfish, *Ptychocheilus oregonensis*	2
31	Razorback sucker, *Xyrauchen texanus*	2
32	Gila topminnow, *Poeciliposis occidentalis*	1
33	Bluegill, *Lepomis macrochirus*	4
34	Fantail darter, *Etheostoma flabellare*	4
35	Greenthroat darter, *Etheostoma lepidum*	1
36	Johnny darter, *Etheostoma nigrum*	4
37	Fountain darter, *Etheostoma rubrum*	1
38	Boreal toad (tadpole), *Bufo boreas*	1

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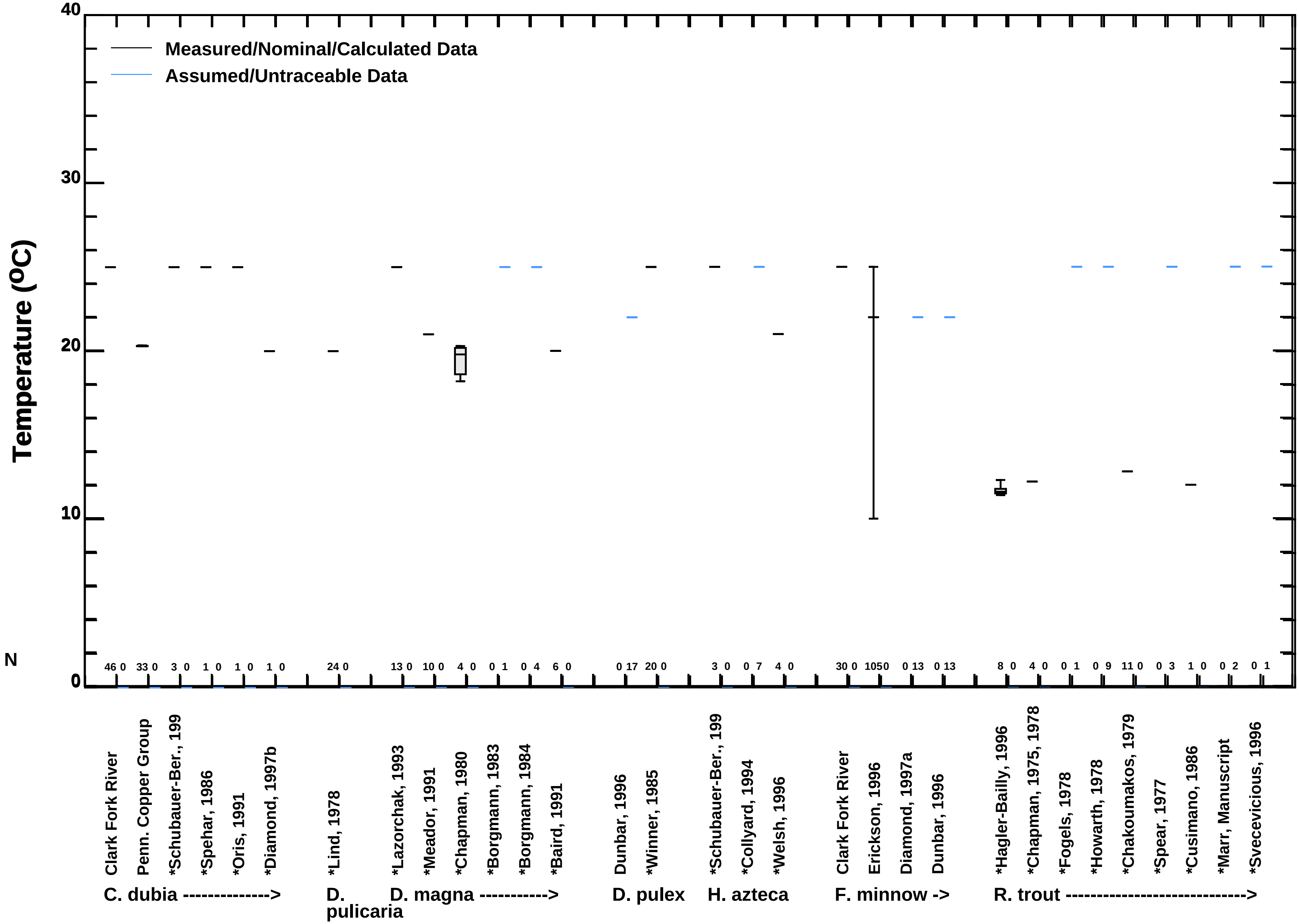
Appendices

Appendix A. Ranges in Calibration and Application Data Sets



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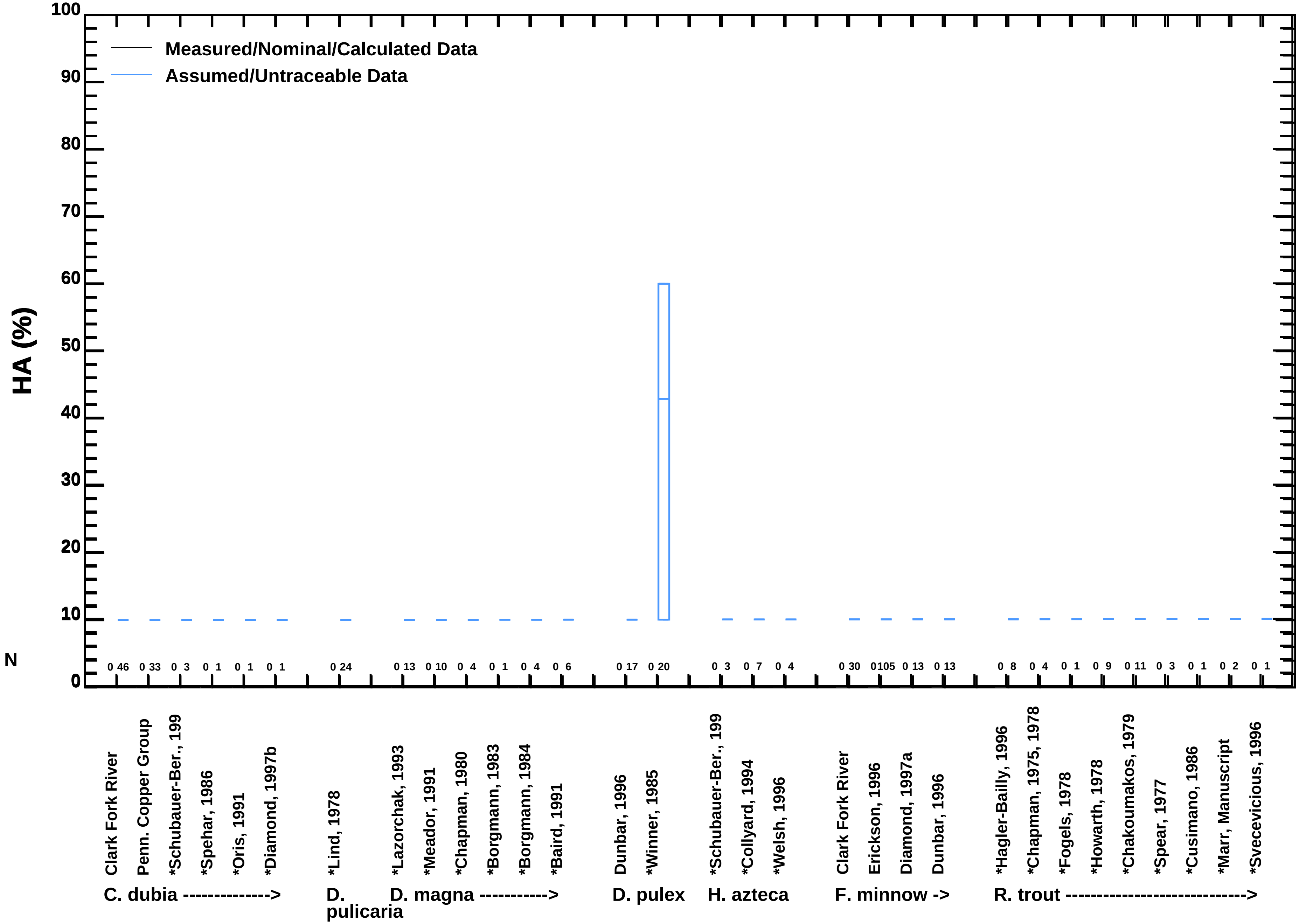

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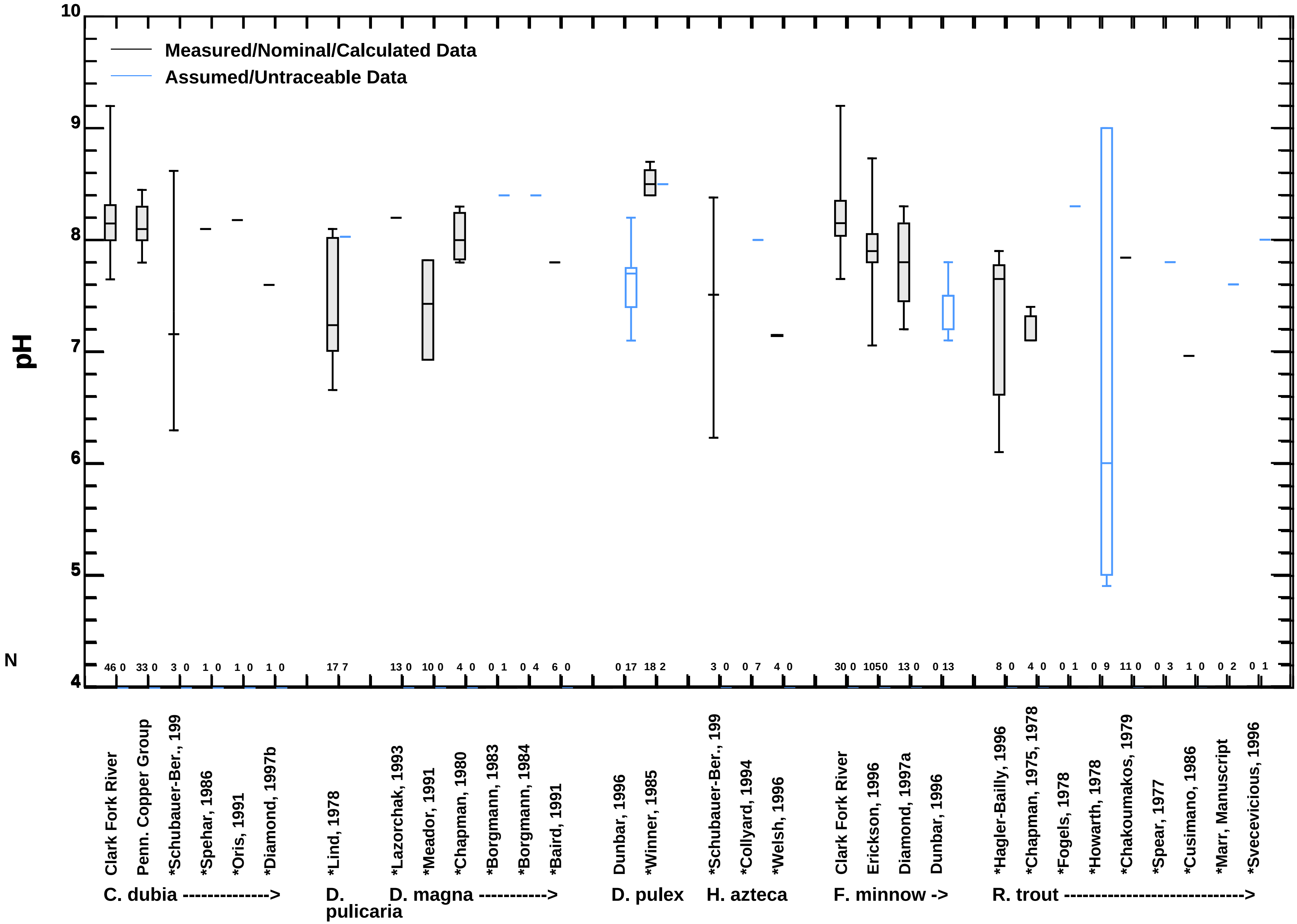

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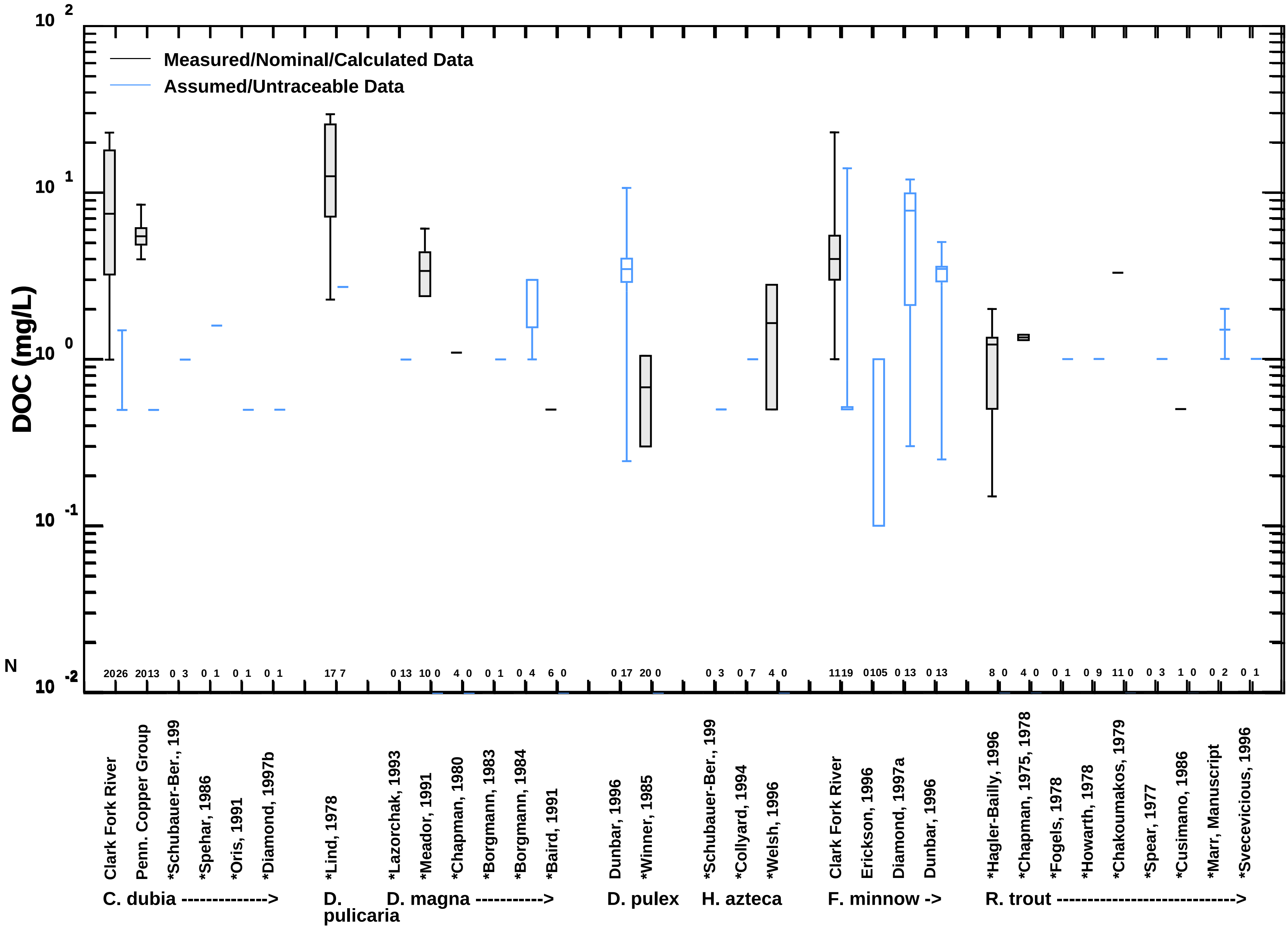

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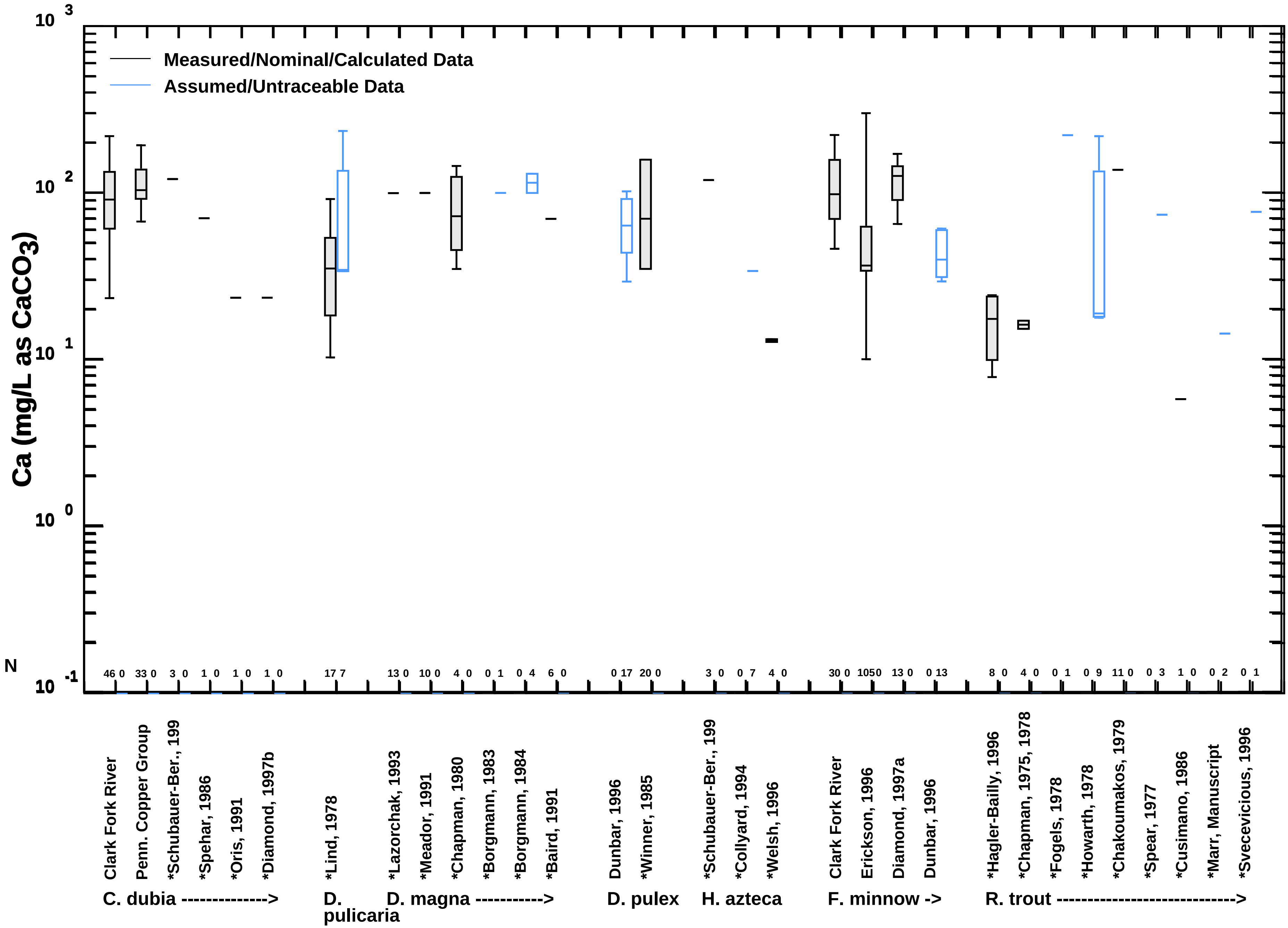

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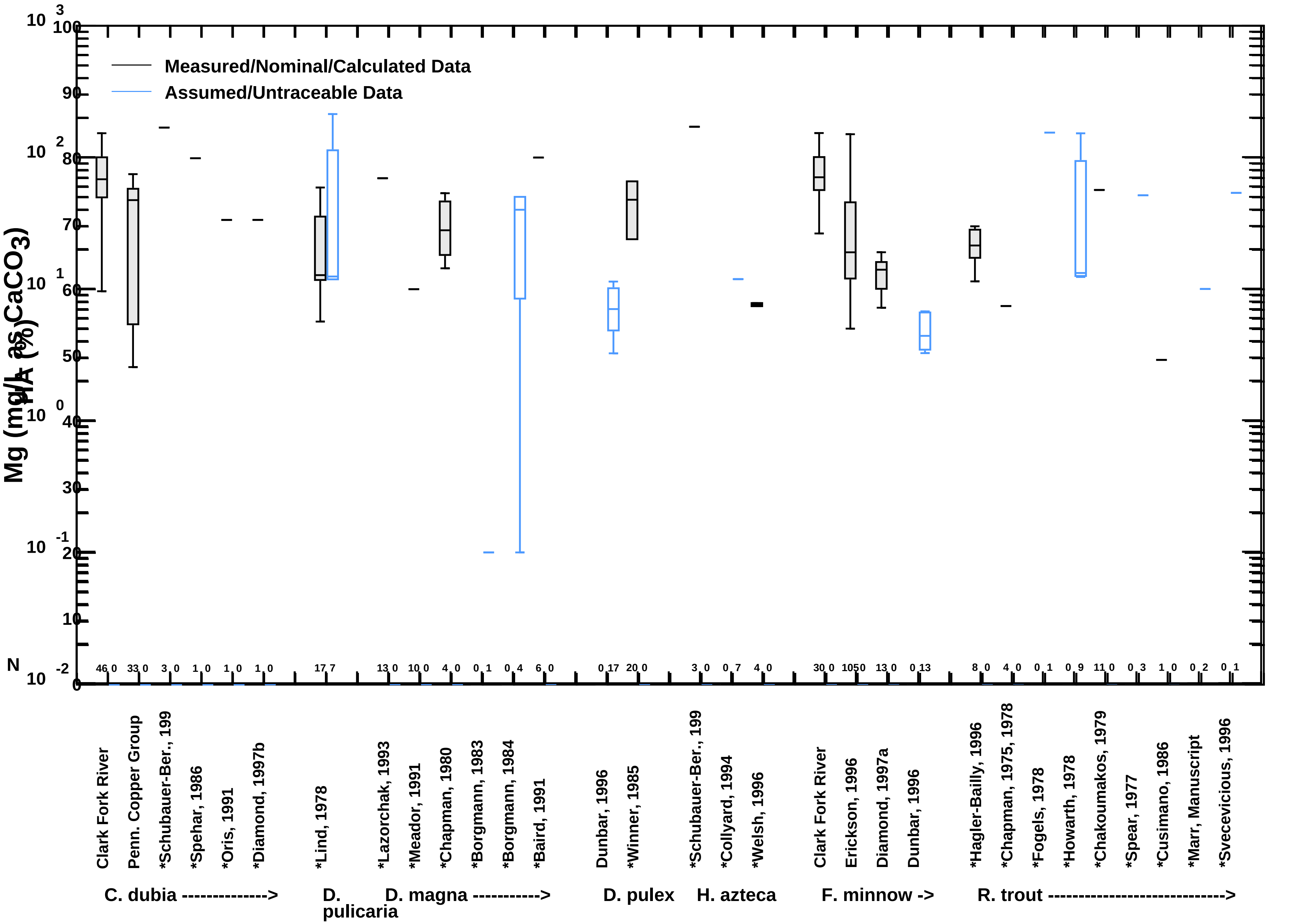

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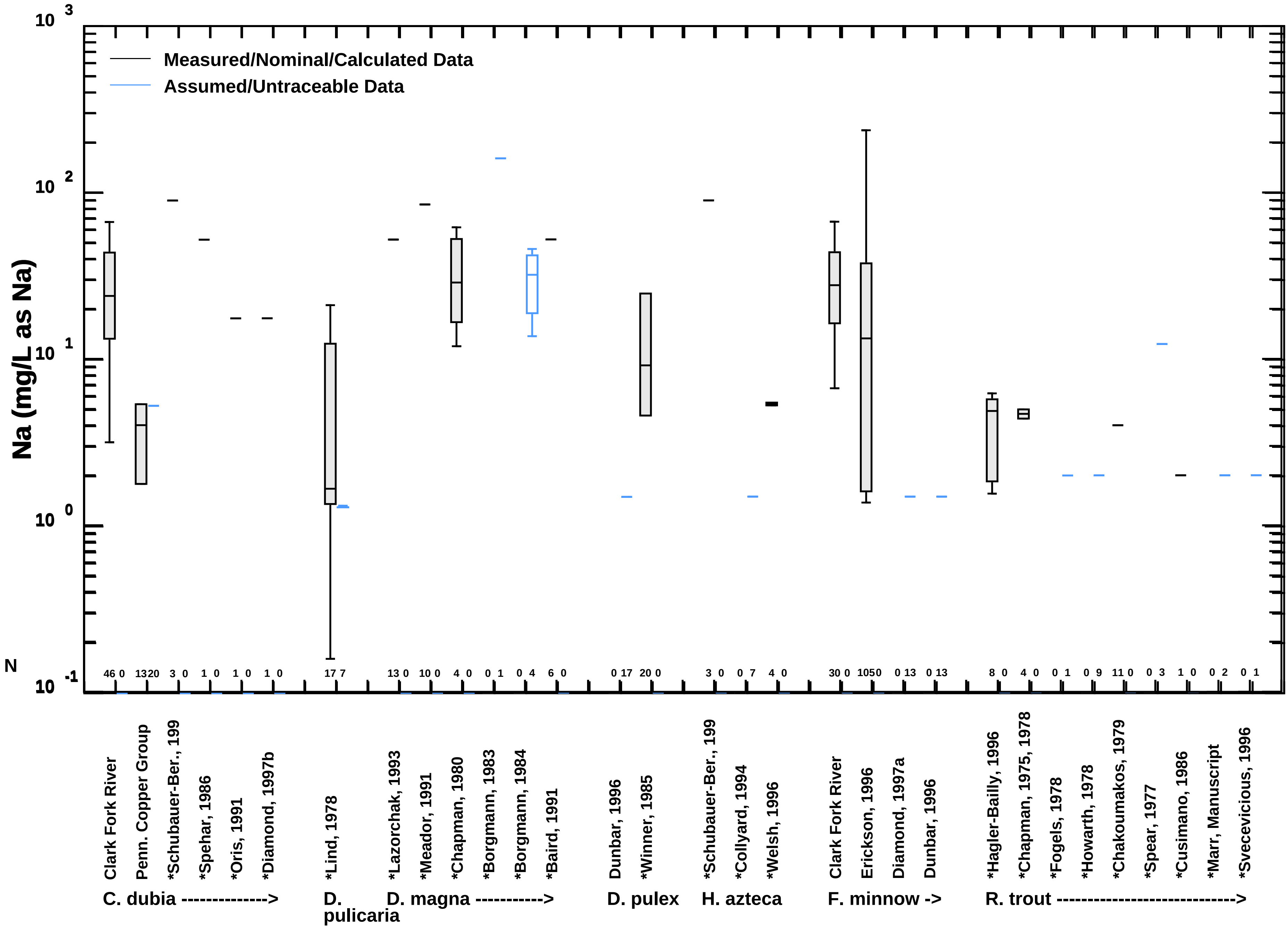

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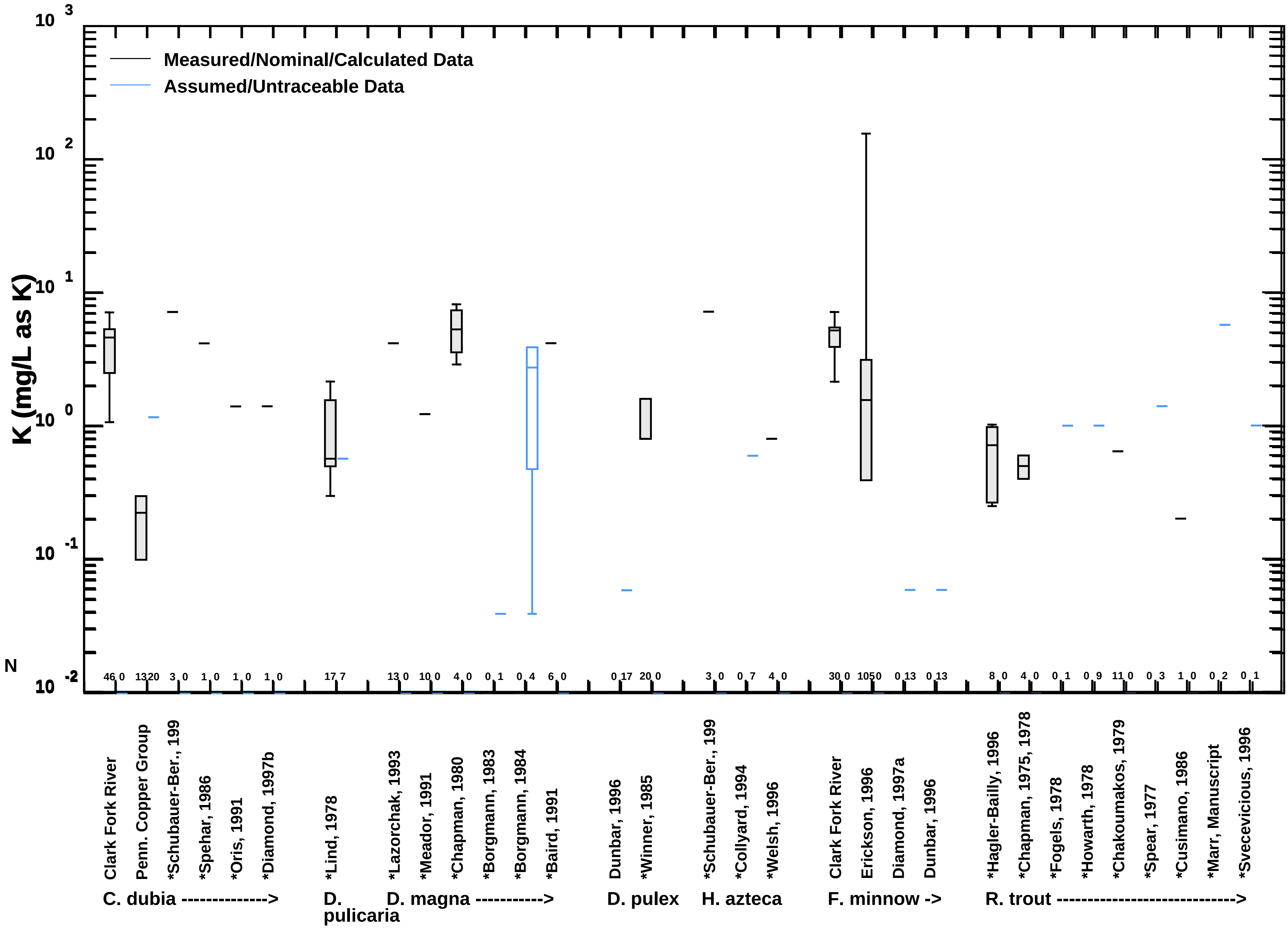

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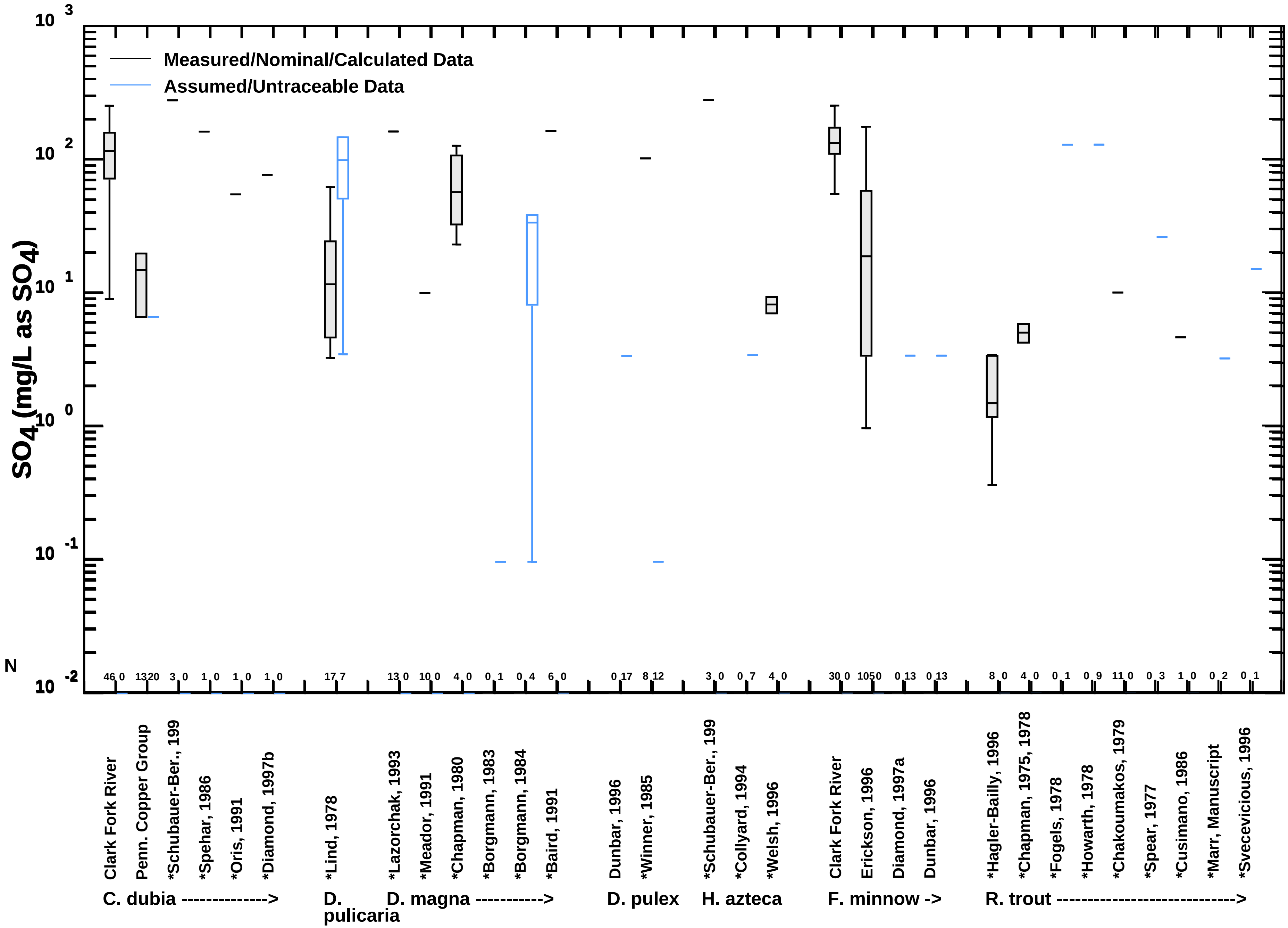

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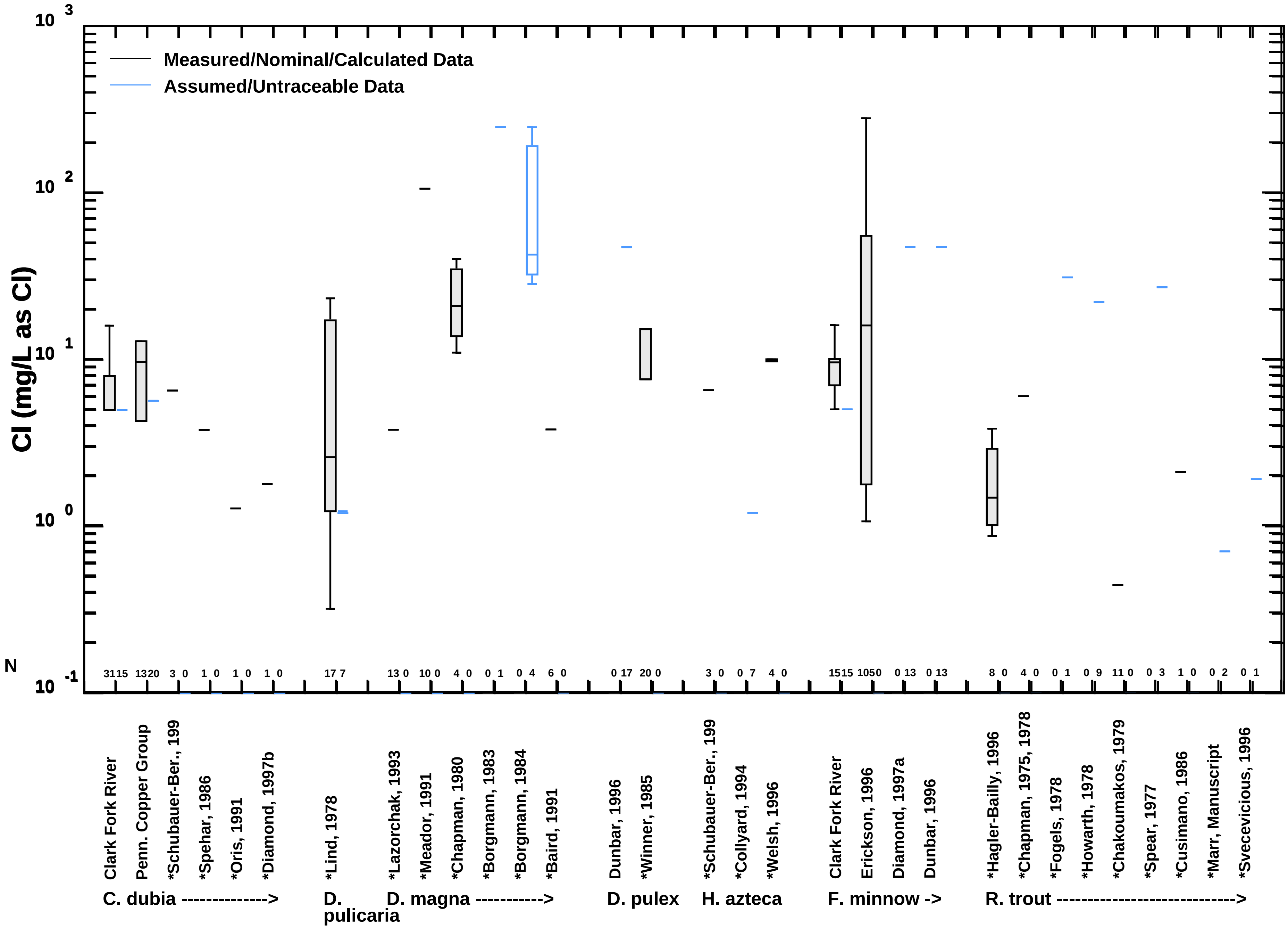

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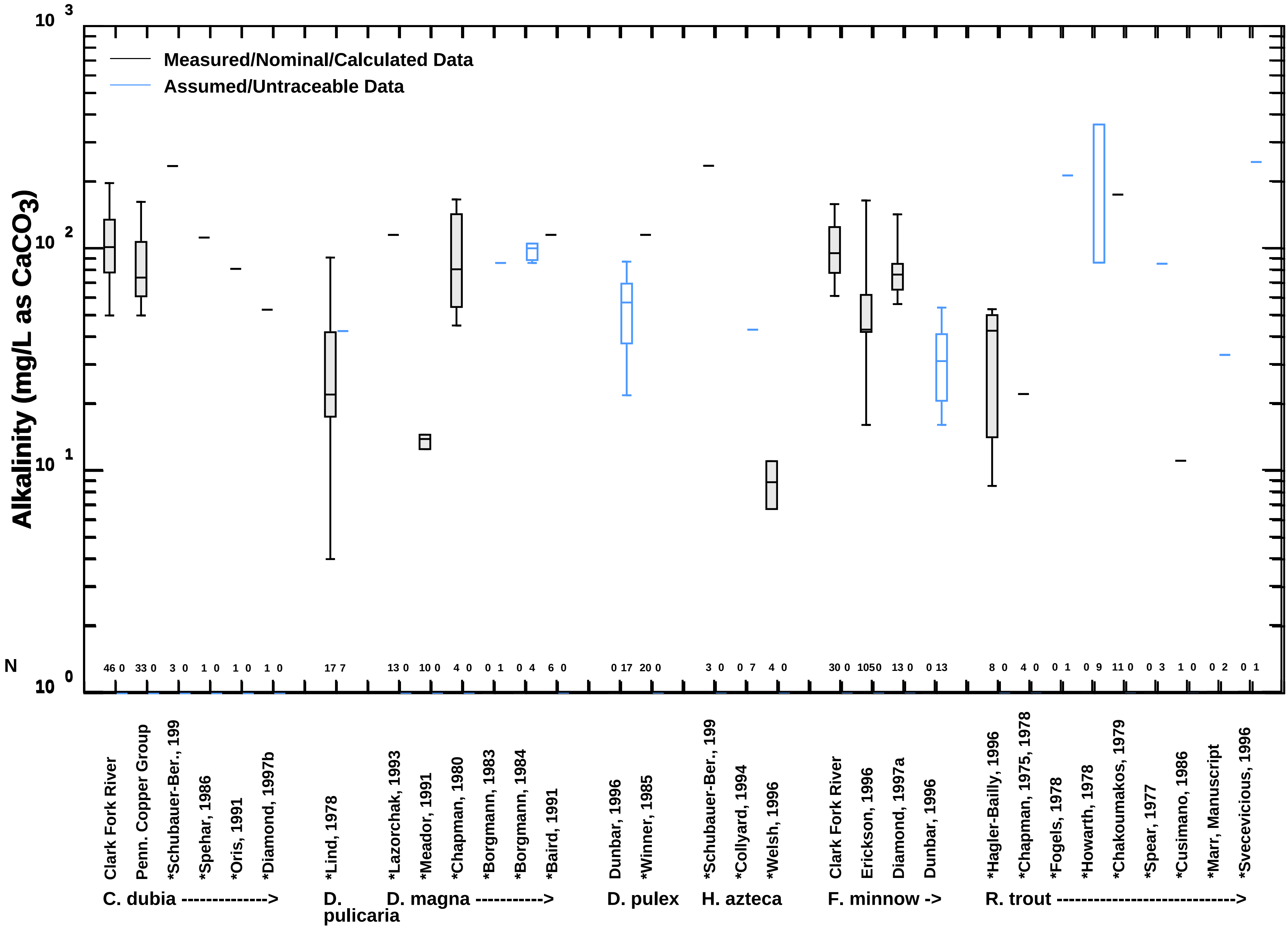

Median, Range and Quartiles of Alkalinity in BLM Calibration and Application Datasets
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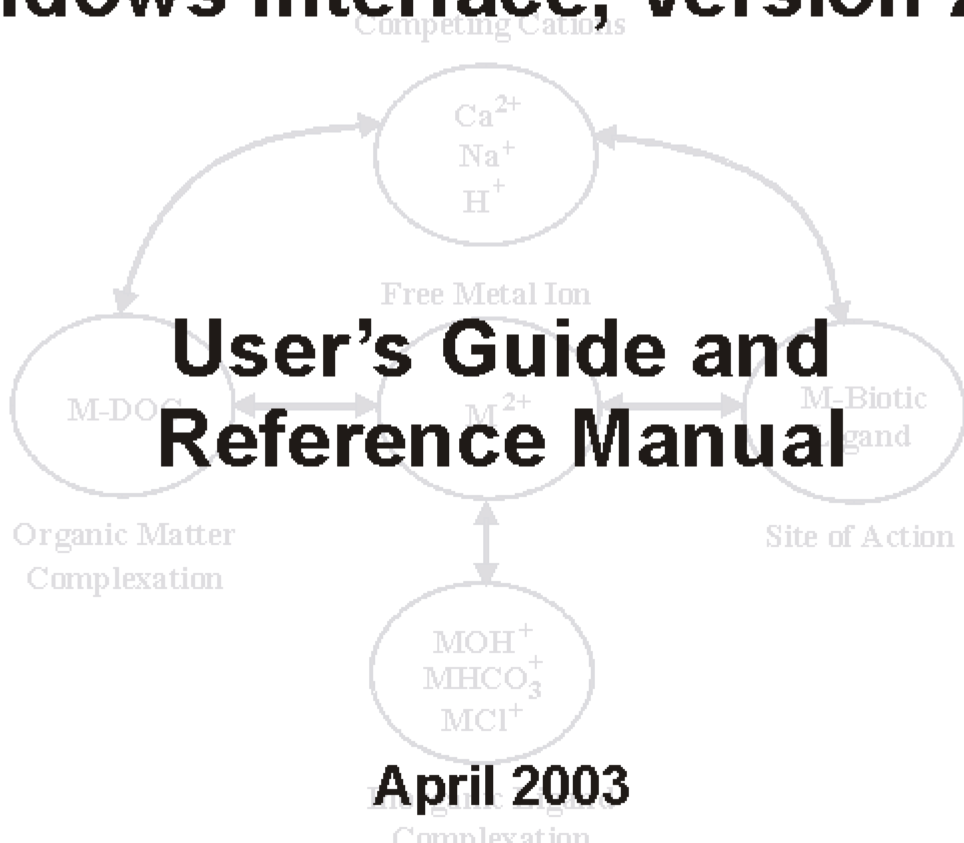
Appendix B. Biotic Ligand Model (BLM) User's Guide

Biotic Ligand Model

Windows Interface, Version 2.0.0



User's Guide and Reference Manual

April 2003

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SECTION 1

INTRODUCTION TO THE BLM

1.1 INTRODUCTION

Metal bioavailability and toxicity have long been recognized to be a function of water chemistry (Sunda and Guillard 1976; Sunda and Hansen 1979). For example, formation of inorganic and organic metal complexes and sorption on particle surfaces can reduce metal toxicity. As a result, metal toxicity can be highly variable and dependent on ambient water chemistry when expressed as total or dissolved metal concentration. In contrast, the effects of water chemistry on metal toxicity can often be reduced or eliminated when metal toxicity is related to free metal ion concentrations (Sunda and Guillard 1976). Allen and Hansen (1996) have shown the relationship between metal speciation and toxicity and have used this relationship to predict the range of effects that site-specific water quality characteristics can have on copper toxicity.

1.2 BLM FRAMEWORK AND CONCEPTUAL MODEL

The Biotic Ligand Model (BLM) was developed to incorporate metal speciation and the protective effects of competing cations into predictions of metal bioavailability and toxicity (Di Toro et al. 2001). A formal description of metal-organism interactions, now commonly referred to as the Free Ion Activity Model (FIAM), was described by Morel (1983a). Pagenkopf (1983), using a similar approach, applied the Gill Surface Interaction Model (GSIM) to predict metal effect levels over a range of water quality characteristics. The BLM is founded upon the principles that underlie these earlier models. The BLM incorporates a version of CHESS (Santore and Driscoll 1995) that has recently been modified to include the chemical and electrostatic interactions described in WHAM (Tipping 1994). The BLM includes reactions that describe the chemical interactions of copper and other cations to physiologically active sites (or “biotic ligands”) which correspond to the proximate site of action of toxicity. However, inorganic and organic ligands can also bind metal, thereby reducing accumulation at the biotic ligand. By incorporating the biotic ligand into a chemical equilibrium framework that includes aqueous metal complexation, the relation between free metal ion concentrations and toxicity is an inherent feature of the model.

The BLM framework also incorporates the competitive effects of other cations that interact with the biotic ligand to mitigate toxicity. For example, at a fixed free metal concentration, as hardness increases, the increased Ca^{2+} competes with the free metal for binding sites at the biotic ligand. A higher free metal concentration is therefore required to achieve the same toxic effect in the presence of elevated Ca^{2+} concentration. The BLM uses this competitive mechanism to simulate the reduction in metal toxicity due to elevated hardness concentrations. Thus, the BLM can effectively account for reduction in metal toxicity due to elevated levels of hardness cations (Meyer et al. 1999).

The BLM has been developed using published information on metal toxicity and biotic ligand accumulation as a function of water chemistry. The most comprehensive data compiled to date for use with the BLM is for copper toxicity to fathead minnows (*Pimephales promelas*). Copper accumulation on the gill has been associated with respiratory distress and decreased blood plasma Na concentrations due to interference with these sites (Playle et al. 1992). The adsorption of copper on gill surfaces in the BLM has been calibrated to measurements of copper accumulation on the gill over a wide range of water quality conditions (Playle et al. 1992, 1993b). Additionally, MacRae (1994) established a dose response relationship necessary to determine the biotic ligand LC50 in rainbow trout. In the BLM, metal toxicity is defined as the amount of metal necessary to result in accumulation at the biotic ligand equal to the biotic ligand LC50. While others have developed models capable of predicting metal bioaccumulation on the gill in short term exposures (Playle et al. 1993a, b), the BLM is the first that includes a scheme for predicting toxicity. The BLM for other metals and organisms is based on a similar approach.

1.3 PREDICTION MODE

The BLM interface application allows the user to run the BLM either in toxicity mode or in the speciation mode. When run in the toxicity mode, for the metal and organism specified by the user, the BLM will predict the amount of metal required to cause acute mortality in the water specified by the user. However, when the BLM is run in the speciation mode, for the metal concentration specified by the user, the BLM will predict the organic and the inorganic speciation in the water column.

1.4 BLM APPLICATIONS

In summary, the BLM can be used to calculate the chemical speciation of a dissolved metal including complexation with inorganic and organic ligands, and the biotic ligand. The biotic ligand represents a discrete receptor or site of action on an organism where accumulation of metal leads to acute toxicity. The BLM can therefore be used to predict the amount of metal accumulation at this site for a variety of chemical conditions and metal concentrations (i.e. the inorganic, organic, and biotic speciation of metals in aquatic settings).

According to the conceptual framework of the BLM, accumulation of metal at the biotic ligand at or above a critical threshold concentration leads to acute toxicity. This critical accumulation on the biotic ligand is also termed the LA50, the Lethal Accumulation of metal on the biotic ligand that results in 50% mortality in a toxicological exposure. The LA50 is expressed in units of nmol/g wet weight of the biotic ligand. Since the BLM includes inorganic and organic metal speciation and competitive complexation with the biotic ligand, the amount of dissolved metal required to reach this threshold will vary, depending on the water chemistry. Therefore, in addition to calculating chemical speciation, the BLM can also be used to predict the concentration of metal that would result in acute toxicity within a given aquatic system.

SECTION 2

OVERVIEW AND HELP FILE LAYOUT

2.1 WHAT'S NEW IN THIS DISTRIBUTION?

Originally, the BLM was developed as an MS-DOS based program, with the user developing the BLM input files using an external spreadsheet program such as Microsoft Excel, running the BLM in the MS-DOS environment, and then analyzing the BLM output using a different set of software tools. However, in order to facilitate data-entry, model simulations, and the analysis of model output in a common application environment and in a more efficient and user-friendly fashion, a graphical user interface was developed for the BLM and first distributed as BLM, Windows Interface Version 1.0.0. The current distribution, Version 2.0.0, is an updated version that offers additional options for data inputs and model simulations. The new functionalities are further described in the subsequent sections. The BLM, Windows Interface Version 2.0.0 incorporates the most current version of the BLM, Version APE8.

Note that BLM datafiles created using the older version of the BLM Windows Interface can be used directly with the new version.

2.2 HELP FILE LAYOUT

The remainder of this document describes the hardware and software requirements for installing and running the BLM Windows Interface, the data requirements of the BLM, a step-by-step guide to using the various functionalities of the BLM Windows Interface and a walk-through of the application using an example BLM datafile.

SECTION 3

SETUP AND INSTALLATION

3.1 SYSTEM REQUIREMENTS

The BLM Windows Interface is designed for use on the IBM compatible PC family of microcomputers running Microsoft Windows. The memory requirements of the BLM Windows Interface are modest and should not interfere with other resident programs. The minimum hardware and software requirements and the recommended system configurations are described below.

Minimum System Requirements
- PC Compatible, Intel Pentium 233 MHz
- Microsoft Windows 95 or higher
- 32 MB RAM
- 30 MB free disk space

Recommended System Configuration
- Intel Pentium 3 or higher, 500 MHz or faster
- 64 MB RAM
- 100 MB free disk space

Even though the BLM Windows Interface can be run on a system with the specified minimum requirements, in the interest of computation time, the recommended system configuration or a higher one would be ideal.

3.2 INSTALLING THE BLM WINDOWS INTERFACE

- **Installing from a disk -** To install the BLM Windows Interface from a CD-ROM, insert the installation disk into the CD-ROM drive. In case the installation does not start up automatically, locate and run the program “setup.exe” located in the main directory in the installation disk by simply double clicking on the file name.

- **Installing from the self-extracting (.exe) file -** To install the BLM Windows Interface from the self-extracting file “BLMWindowsInterface_Version2.0.0.exe” simply double click on the file to extract its contents to a temporary folder. This temporary folder can be deleted once the installation is completed. To start the installation, locate and run the program “setup.exe” located in the temporary folder by simply double clicking on the file name.

Note that on PCs running Microsoft Windows 2000 and higher or any version of Microsoft Windows NT, the user may have to be logged on as the “Administrator” or have the relevant permissions to modify the “System” directory in order to install the necessary files.

The setup program will guide the user through a fairly straightforward installation process, querying the user for information on where to install the necessary files. During the installation, a shortcut to the BLM Windows Interface application will be added to the “Programs” sub-menu within the “Start” menu on the Microsoft Windows desktop. In addition, the BLM Windows Interface application will also be registered in the system registry so that the BLM datafiles created by the user can be accessed directly by just double clicking on the file name.

SECTION 4

DATA REQUIREMENTS

The BLM predicts metal toxicity and speciation for a particular site based on the ambient water quality. Therefore, the user will be expected to provide data describing the physical and chemical properties of the site water. The data requirements of the BLM are conventional physical and chemical parameters that are easily measurable in the laboratory. This section describes the general physical and chemical data requirements for an application of the BLM to predict metal speciation and toxicity in aquatic systems.

4.1 WATER QUALITY PARAMETERS REQUIRED

The ambient water quality information required to run the BLM is listed below:

- Temperature
- pH
- Dissolved Organic Carbon
- Major cations (Ca, Mg, Na, and K)
- Major anions (SO_4 and Cl)
- Alkalinity
- Sulfide

For a given metal some of these chemical inputs have an important effect on determining metal speciation, while other chemical inputs have only minor effects on BLM predictions. The user should be aware of the relative importance of each of the chemical inputs to decide whether adequate information is available for a meaningful application of the BLM. The guidelines described in the subsequent sections may be helpful in that assessment.

Each water sample has to be fully described in terms of the above water quality inputs before the BLM can be used. However, if some of the parameters are known to be absent in the water sample, a nominal, negligible concentration should be input (a value on the order of 1E-10 mg/L should suffice typically) rather than a zero concentration.

4.1.1 Temperature

Temperature measurements are typically the most common and basic of all water quality measurements and therefore available in most laboratory characterizations of site-water chemistry. Since the BLM is based on a thermodynamic chemical equilibrium modeling framework, temperature measurements are important to determine the relevant thermodynamic reaction rates.

4.1.2 pH

Accurate pH values are important to BLM results for most metals. The chemical speciation of many metals, such as copper, is directly affected by pH. However, pH is also important to determine the metal complexation capacity of dissolved organic matter. It is also important to determine the speciation of inorganic carbon, which relates to the formation of metal carbonate complexes. For these reasons, pH is a required chemical input to the BLM. If BLM results are to be compared to laboratory measurements of metal toxicity, then it is preferable that the pH is measured within the test chamber during the exposure.

4.1.3 Dissolved Organic Carbon

Dissolved organic matter plays a critical role in determining metal speciation and bioavailability. In the BLM, the presence of dissolved organic matter is specified as a dissolved organic carbon (DOC) concentration in mg/L and is a required input for the BLM. For water with low DOC it is important to make sure that analytical detection limits are sufficiently low. In toxicity studies, the test organisms themselves may be a significant source of organic matter depending on the number of organisms and the volume of the test chamber.

Humic Acid Fraction of DOC

The BLM uses a description of organic matter chemistry developed for the Windermere Humic Aqueous Model (WHAM, Version 1.0), which characterizes metal complexation with both humic and fulvic organic matter sources. It is therefore necessary to specify the distribution of humic and fulvic acids in the organic matter present in a given water. Unfortunately, natural organic matter composition is not routinely characterized and information on humic and fulvic acid content is not likely to be available. In the absence of chemical characterization, a value of 10% humic acid content is recommended for most natural waters. The variability of the dissolved organic matter content in diverse water sources is a topic of current study by BLM investigators.

4.1.4 Metal Concentrations

The BLM can be used to predict the speciation and bioaccumulation of metals when a metal concentration is provided as an input. When the model is used in metal speciation mode, metal concentrations are a required input. However, the BLM model is probably most useful as a means of predicting metal toxicity (i.e., a concentration associated with a specific toxicological effect). When used in metal toxicity mode, there is no need to input metal concentrations.

4.1.5 Major Cations

The cations Ca, Mg, Na, and K are all necessary inputs to the BLM. For copper and silver, Ca and Na can directly compete with the metal at biotic ligand sites and these cations will, therefore, have a direct effect on predictions of metal toxicity. For some organisms, Mg may play a critical role as well. These cations, therefore, are required inputs to the BLM. On the other hand, K currently has no direct effect on metal toxicity in the BLM and can be estimated if measurements do not exist.

4.1.6 Major Anions

The anions SO_4 and Cl are necessary inputs to the BLM (although bicarbonate is also an important anion, it is discussed separately below). In freshwaters, SO_4 may be the dominant anion and is, therefore, important for determining charge balance and ionic strength. The chemistry of metals and of natural organic matter is dependent to varying degrees on ionic strength and so SO_4 has some importance as a BLM input. However, if measurements of SO_4 are not available, the concentrations can be estimated. For copper simulations, Cl is only important as a contribution to ionic strength, but for silver simulations Cl can have an additional importance due to the formation of silver-chloride complexes. Therefore, it is preferable that only measured Cl concentrations are used for BLM applications involving silver, while estimates can be used for applications involving copper.

4.1.7 Alkalinity

Inorganic carbon species in the BLM include carbonate (CO_3), bicarbonate (HCO_3), and carbonic acid (H_2CO_3). The sum of these species is called dissolved inorganic carbon (DIC). Bicarbonate is usually the most important DIC species in natural waters since it is the dominant species between pH 6.35 and 10.33. Inorganic carbon is a critical input to the BLM since many metals, including copper, form carbonate complexes. Silver, on the other hand, does not form carbonate complexes, and so DIC is not a critical input to BLM applications for silver. Unfortunately, measurements of DIC are not often made in natural water samples. However, if it can be reasonably assumed that carbonate alkalinity is the dominant source of the measured alkalinity, the DIC can be estimated from alkalinity and pH measurements as in the equation below.

$$DIC = Alk \cdot \frac{\frac{H}{K1} + 1 + \frac{K2}{H}}{1 + \frac{2 \cdot K2}{H}}$$

where Alk. = alkalinity in equivalents/L
= 2×10^{-5} x alkalinity (as mg $CaCO_3$ / L)
H = 10^{-pH}
K_1 = $10^{-6.352}$
K_2 = $10^{-10.329}$

The BLM Windows Interface uses this expression to calculate the DIC internally, and so only the alkalinity and the pH need to be specified. Alkalinity should be measured on filtered samples to eliminate potential contribution from suspended $CaCO_3$ and specified in units of mg/L of $CaCO_3$. However, depending on the inorganic carbon option selected, the user may also opt to specify DIC concentrations directly. This latter option would be preferred generally, and especially when carbonate alkalinity is not the dominant source of measured alkalinity, but must depend on reliable measurements of DIC.

4.1.8 Sulfide

Although it has traditionally been assumed that sulfide concentrations are negligible in aerated waters, recent evidence suggests that appreciable sulfide concentrations persist in both marine and freshwaters. Waters impacted by wastewater treatment plant effluents in particular can have elevated sulfide concentrations. Sulfide has a strong affinity for many metals and is therefore an important consideration in determining metal speciation and bioavailability. If it is present, measured sulfide should be considered a required input to the BLM, especially when sulfide concentrations are similar to the predicted effect levels for a given metal and organism.

At the present time, researchers at several universities are still looking into the nature of sulfide-metal complexes in aqueous systems. The persistence of sulfide in aerated waters may be linked to the formation of stable metal-sulfide clusters, and these clusters may not be detected by traditional sulfide measurements. Alternatively, strong metal complexes that are believed to be due to sulfide compounds may be due to other forms of reduced sulfur that are also missed by traditional sulfide measurements. Suitable analytical methods that measure the target form of sulfide and which do not measure other non-reduced forms of sulfur, are under development. Also, sulfide levels in some locations may be known to be low and well below the effect levels of interest for a given metal. Therefore, sulfide measurements may not be critical in all instances. Since these research questions are still being addressed, metal-sulfide reactions have not yet been incorporated into the BLM. The sulfide column in the input file is a reminder that these interactions are likely to be added to a subsequent version of the model. Sulfide concentrations added in that column will not affect the BLM calculation.

SECTION 5

STARTING THE APPLICATION

To start using the BLM Windows Interface, select the application using “Start -----> Programs” on the Microsoft Windows desktop. The user will be presented with the following screen, which contains the user input areas and the various functions implemented in this version of the BLM Windows Interface.

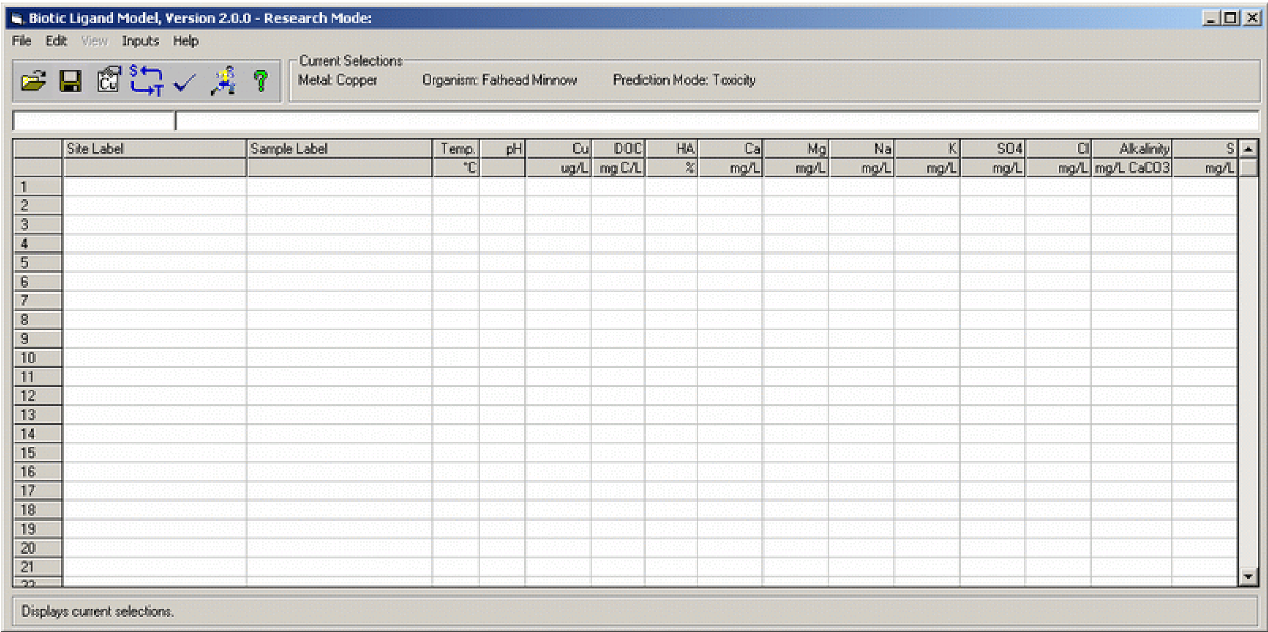

Figure 1: Opening Screen for the BLM Windows Interface Application

In case the user already has a BLM datafile created using the BLM Windows Interface, the file can be opened directly by just double clicking on the file name through a file-system manager such as Microsoft Windows Explorer.

SECTION 6

RUNNING THE APPLICATION

The BLM Windows Interface provides access to the BLM in its full suite of capabilities (i.e., predicting metal speciation and toxicity, predicting Water Effect Ratios (WER), comparison to laboratory measurements of toxicity, calibration to new metals and organisms, etc). Providing an easy-to-use interface and environment for developing datasets of water chemistry information and applying the BLM for predictions of metal speciation and toxicity makes the process of BLM development more efficient and productive.

The following sections describe the various functions and features available in the BLM Windows Interface and the use of the BLM in its various predictive capabilities.

6.1 DESCRIPTION OF INTERFACE

Figure 2 shows a snapshot of the BLM Windows Interface application. The main purpose of this section of the interface application is to provide an easy-to-use editor to develop input files containing water chemistry information for the BLM, to facilitate checks and validate the user inputs for the various parameters, to perform checks on whether the values entered for any given parameter are within the range for which the BLM has been calibrated, and to run the BLM for predictions of aquatic speciation or toxicity for a variety of metals and organisms.

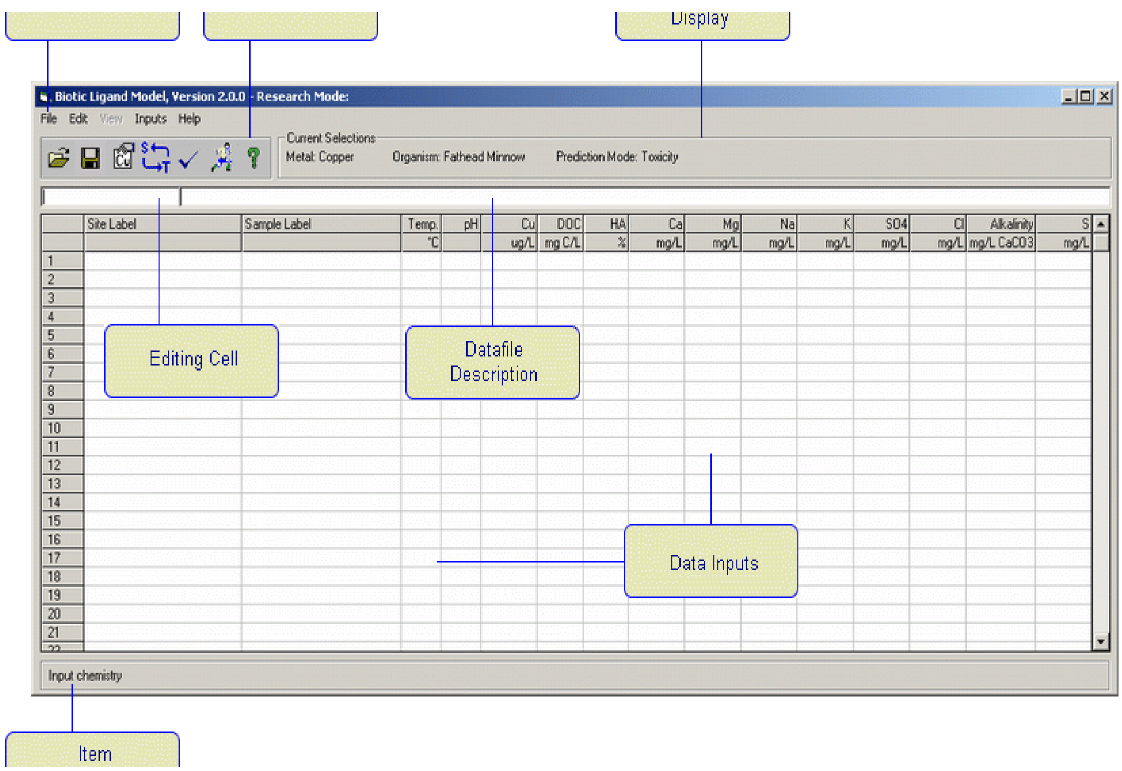

Figure 2: Snapshot of the BLM Windows Interface

As shown in Figure 2, the interface window is divided into seven areas broadly based on their functionality. Each of these is described in the subsequent sections.

6.2 DATA INPUTS

This region of the interface window contains a spreadsheet-based editor, which organizes the various BLM input parameters in a columnar format such that the chemistry for each discrete water sample can be specified on a separate row. Apart from the water chemistry information, two additional columns are also provided for labeling the sites and the samples described in a given BLM datafile. Figure 3 shows the various columns typically available for user input.

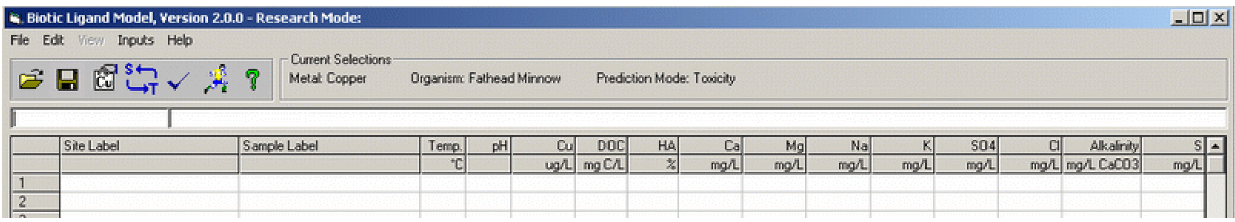

Figure 3: Columns for Data Input in the BLM Windows Interface

6.2.1 Site Label and Sample Label Descriptors

The first column, the "Site Label," is meant to contain information about the site under consideration. For example, it could be the name of the river or it could be the Mile Point along a river if the same file contains water chemistry data for more than one location along a particular river. The information contained within the "Sample Label" field can be used to distinguish the various water chemistry samples available for a particular site. For instance, at a given site, this field could represent the date and time at which the site water samples were collected. However, for both the site and the sample descriptor fields, there is an upper limit of 20 characters that are allowed in each field.

6.2.2 Water Chemistry Inputs

The subsequent columns contain the data input area for the water quality parameters described under Data Requirements. For predictions of metal toxicity, metal concentration is not a required input, since the BLM will predict the amount of metal that results in acute toxicity to the specified organism. However, for predictions of metal speciation, the metal concentration is a required input and if no metal concentration is specified, the row will be considered incomplete and no BLM predictions will be made for that row. For all other water quality inputs, any row with a missing input will be flagged as incomplete and no BLM predictions will be made for that row.

6.3 MENU BAR

Located at the very top of the interface window, the menu bar provides the user with a range of functions and features including:

- Managing the BLM datafiles
- Text editing functions

- Functions to select between various units for data inputs
- A help function

These features are described below in further detail.

6.3.1 File

Figure 4 shows the functions available under this menu item. Basic file management utilities to create a new BLM datafile, to open an existing BLM datafile, and to save a BLM datafile are provided.

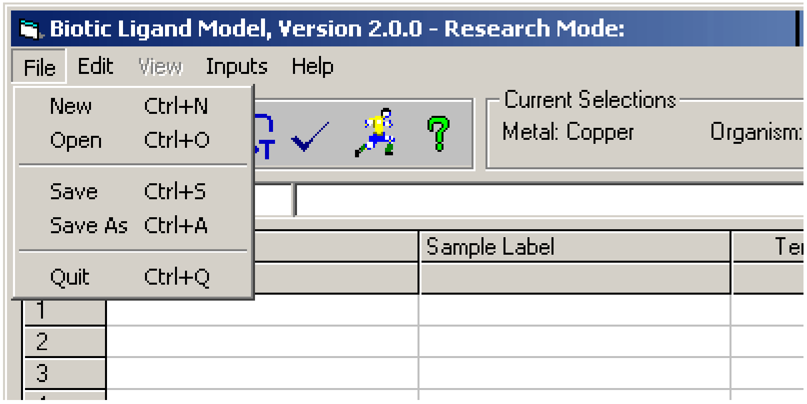

Figure 4: Snapshot of File Menu Item

Shortcut keys (shown to the right of each item) are also implemented for all the different functions in this menu item.

For ease of access, BLM datafiles can also be opened directly by double clicking on the BLM datafile in a file system manager such as Microsoft Windows Explorer. This avoids having to first start the application and then navigate through the file menu to locate the BLM datafile of interest.

Note that the BLM datafiles created by the interface application are given a ".BLM" extension by default. Even though the BLM datafile created by the interface application is basically an ASCII text file, it is recommended that the user not modify this file using a program other than the BLM Windows Interface application. Doing so may result in the BLM datafile getting corrupted and if this happens, the next time the user tries to edit that BLM datafile using the BLM Windows Interface, the file may not be read correctly by the BLM interface application.

6.3.2 Edit

Figure 5 shows the editing functions available in the BLM Windows Interface. Basic editing functions such as "Cut," "Copy," "Paste," and "Delete" are implemented in the interface application.

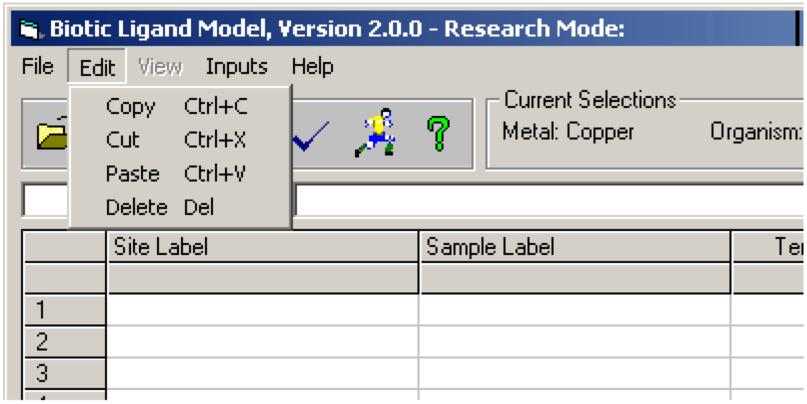

Figure 5: Snapshot of Edit Menu Item

The editing functions can be performed on a single cell or multiple cells selected by highlighting the cells with a mouse click and drag operation or by using the Shift and Arrow functions on the keyboard. These editing functions can also be accessed by using the shortcut keys shown to the right of each item or by clicking the right mouse over the selected data cells and then selecting the editing operation from the editing menu that is displayed. Note that it is also possible to copy and paste data from external programs such as a spreadsheet application into the BLM Windows Interface.

6.3.3 View

This feature is not implemented in the current distribution of the BLM Windows Interface but may be available in subsequent versions.

6.3.4 Inputs

Measurements of the water quality parameters required for using the BLM are often reported with varying units. In order to provide the user with a higher degree of flexibility to develop BLM input files, the BLM interface allows data inputs in several different units by means of this menu item, as shown in Figure 6.

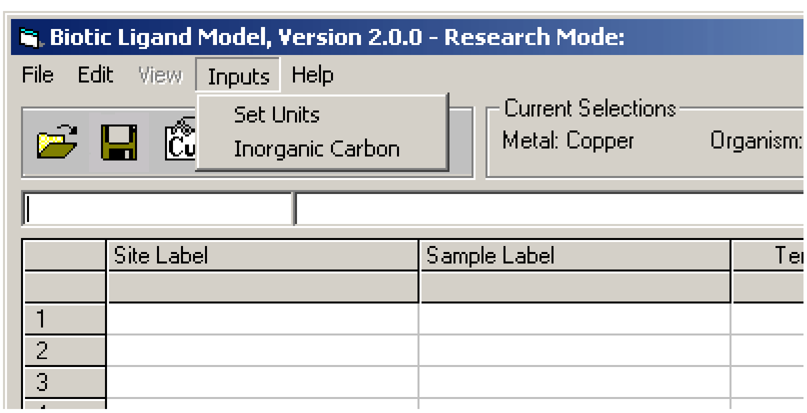

Figure 6: Snapshot of Inputs Menu Item

Units

The first option, “Set Units,” allows the user to select the units for the various BLM input parameters, as shown in Figure 7. For each parameter, the current selected units are highlighted by default and the user can select the desired units from the list of options shown. When changing units for a given parameter, data already input for that parameter is converted to the new units to prevent any loss of data.

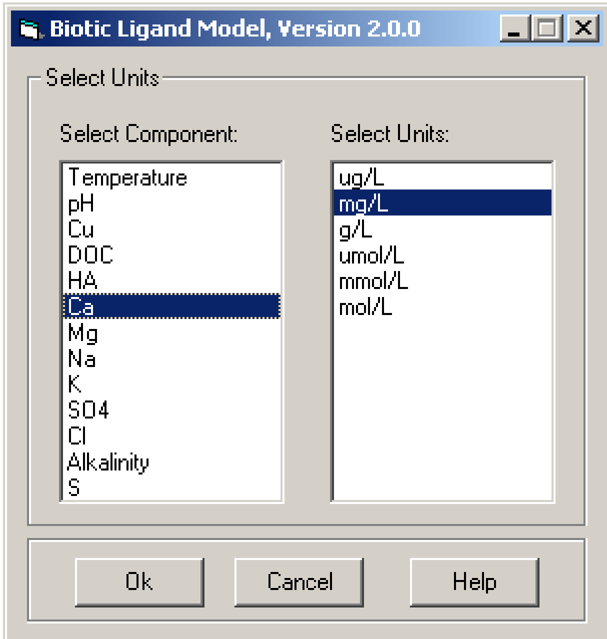

Figure 7: View of a Typical “Set Units” Screen

Inorganic Carbon

The second option, “Inorganic carbon,” gives the user the option to select between various options for specifying the inorganic carbon in the system. As mentioned previously, the BLM simulates the formation of metal-carbonate complexes and therefore inorganic carbon is a required input for BLM simulations. Inorganic carbon in the system can be specified in one of two ways—alkalinity or dissolved inorganic carbon. Accordingly, the user can select between these two options by means of the “Inorganic carbon” feature, as shown in Figure 8.

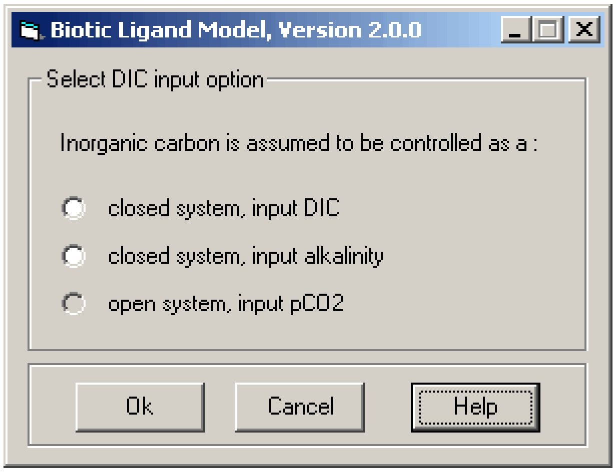

Figure 8: View of Inorganic Carbon Input Options Screen

6.3.5 Help

Figure 9 shows the various features available under the Help menu item.

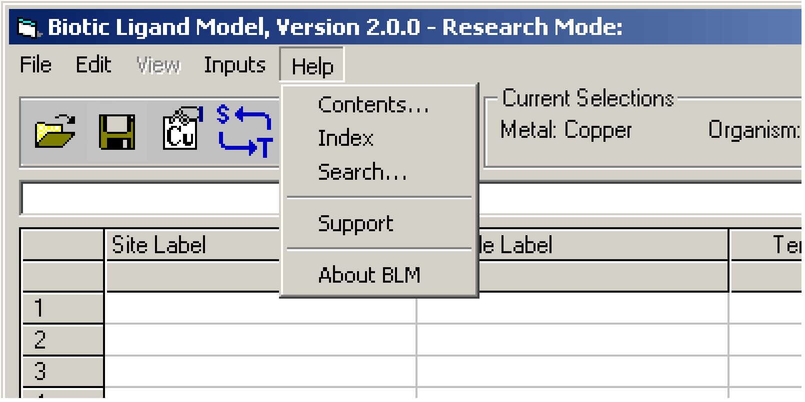

Figure 9: Snapshot of Help Menu Item

The help file for the BLM Windows Interface can be accessed via this menu item and can be browsed by its contents, by a keyword index, or by searching for a particular word or phrase. In addition, under the "Support" sub-item, there is also information on whom to contact for technical support and sending bug reports, etc. A short description of the BLM can be found under the sub-item "About BLM."

6.4 SHORTCUTS MENU

This group of icons contains shortcuts to some of the menu bar items and some additional functions that are not available on the menu bar. Figure 10 shows the various icons and their functions.

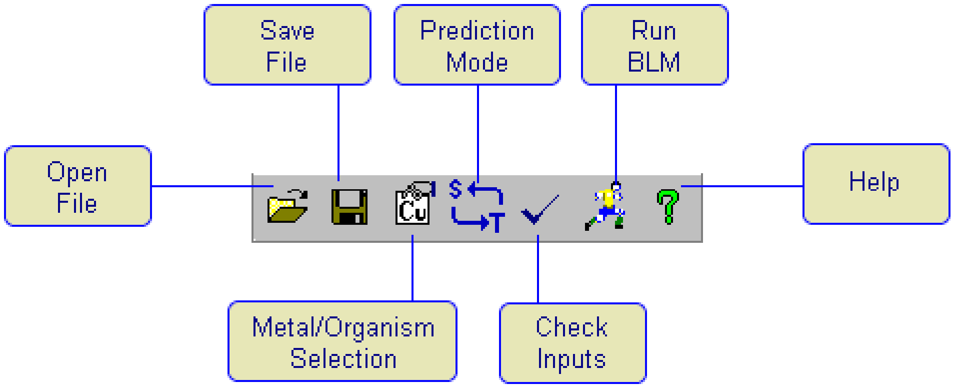

Figure 10: Shortcut Menu Icons

6.4.1 Open File

This is a shortcut to the menu bar item under "File -----> Open" and is provided for a quick mode of access to the BLM datafiles. In case the BLM datafile being edited by the user has changed since the last time it was saved, the user will be queried for a confirmation on whether to proceed to open another datafile with or without saving the current datafile.

6.4.2 Save File

This is a shortcut to the menu bar item under "File -----> Save" and is provided for a quick mode of saving the BLM datafiles. The datafile will be saved under the same name it was last saved as. In case the user wishes to save the file under a different file name, the menu bar item "File -----> Save As" should be chosen.

6.4.3 Metal/Organism Selection

As mentioned previously, the BLM can be used to study the toxicity and speciation for a variety of metals and organisms. This action button is provided to allow the user to select the metal and the organism for which toxicity or speciation has to be predicted. Clicking on this icon will present the user with the window shown in Figure 11 and the user can choose the desired metal and organism for the BLM predictions. The current metal and organism selections are displayed in the Current Selection Display area.

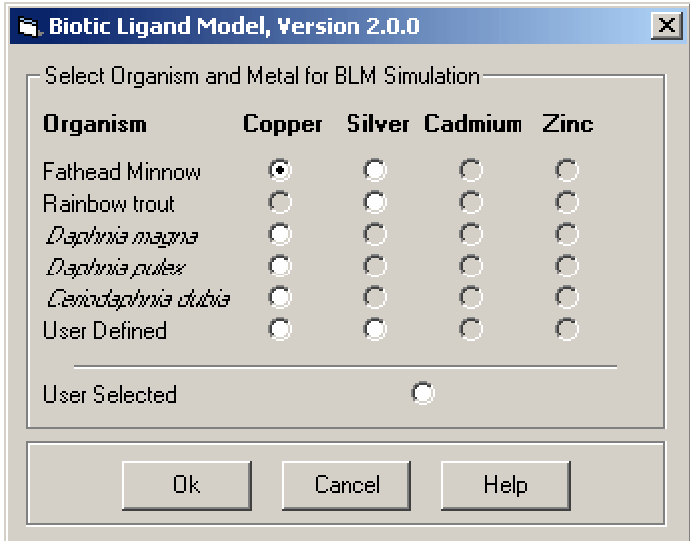

Figure 11: Metal and Organism Selection Options

Metal and Organism Options Available

The metal- and organism-specific parameter files that are distributed along with the current distribution of the BLM Windows Interface, Version 2.0.0 are indicated by the options that are not grayed out in Figure 11, i.e., the combinations available for the user to choose from. Note that these metal and organism specific parameter files are part of an ongoing task of refining the calibration and application of the BLM and may therefore undergo revisions from time to time. The metal and organism selections made by the user are also saved in the BLM datafile and the next time the user opens the BLM datafile, the application will default to the selections made by the user at the time the file was saved.

It is advisable to develop separate BLM datafiles for separate metals even though the application of the BLM may be for the same set of observations. The current distribution of the BLM can be applied to only one metal at a time. Since the input metal concentrations are specified in units of mg/L, the interface application internally converts these to units of mols/L using the molecular weight for the metal selected by the user. Changing the metal for the BLM application within an existing datafile developed for a different metal may result in an erroneous conversion from units of mg/L to mols/L when the user saves and opens the datafile the next time.

User Defined

Normally, when run in the toxicity prediction mode for a given organism and metal, the BLM interface application will derive the LA50 for the user selected organism from the parameter file specific to that particular metal and organism. The BLM will then predict the LC50 of the selected metal to the selected organism for all the observations with a complete set of BLM input parameters. However, in order to provide additional flexibility in operation, the BLM can be run for a given metal with different LA50s for different rows of input. That is, the BLM will predict LC50s corresponding to different LA50s for each row. This is accomplished by selecting the “User Defined” option shown in Figure 11 and selecting “Ok.” This will add an extra column to the spreadsheet editor in the application window in the very last column position, to the extreme right. The user is expected to populate this column for each row of input, with the desired LA50. Note that leaving this column blank for any line of input can result in the BLM treating that line of input as a incomplete input and will result in failure to predict toxicity.

User Selected

In addition to the metal- and organism-specific parameter files that are distributed along with the current distribution, users may also opt to develop and use their own versions of these files for BLM predictions. This is achieved by selecting the "User Selected" option shown in Figure 11 and selecting "Ok." The user will then be queried for the location of the desired parameter file. New parameter files can be developed by the user along the lines of the parameter files supplied with this distribution (files with the extension ".DAT" located in the "Model" sub-directory within the BLM home directory).

6.4.4 Prediction Mode

The BLM interface application allows the user to run the BLM either in toxicity mode or in the speciation mode. When run in the toxicity mode, for the metal and organism specified by the user, the BLM will predict the amount of metal required to cause acute mortality in the water specified by the user. However, when the BLM is run in the speciation mode, for the metal concentration specified by the user, the BLM will predict the organic and the inorganic speciation in the water column.

The "Prediction Mode" button allows the user to toggle between the speciation and toxicity prediction modes in the BLM. The current prediction mode is also displayed in the Current Selection Display area. By default, the BLM interface application assumes that the BLM prediction mode is the toxicity mode unless the user specifies otherwise. The current prediction mode is also saved in the BLM datafile and the next time the user opens up the BLM datafile, the application will default to the prediction mode at the time the file was saved.

6.4.5 Check Inputs

After creating a BLM datafile, the user may wish to check the water chemistry inputs to verify if the parameter values are within the overall range for which the BLM has been calibrated and to check to see if all the parameters necessary for a BLM prediction have been specified. Clicking on this icon serves to generate an input check report which contains information on what parameters are out of range (too high or too low when compared to range for which the BLM has been calibrated) and what parameters are missing for any given row of input. The range of parameter values for which the BLM has been calibrated is described in Input Check Range. Figure 12 shows an example of such an input check report.

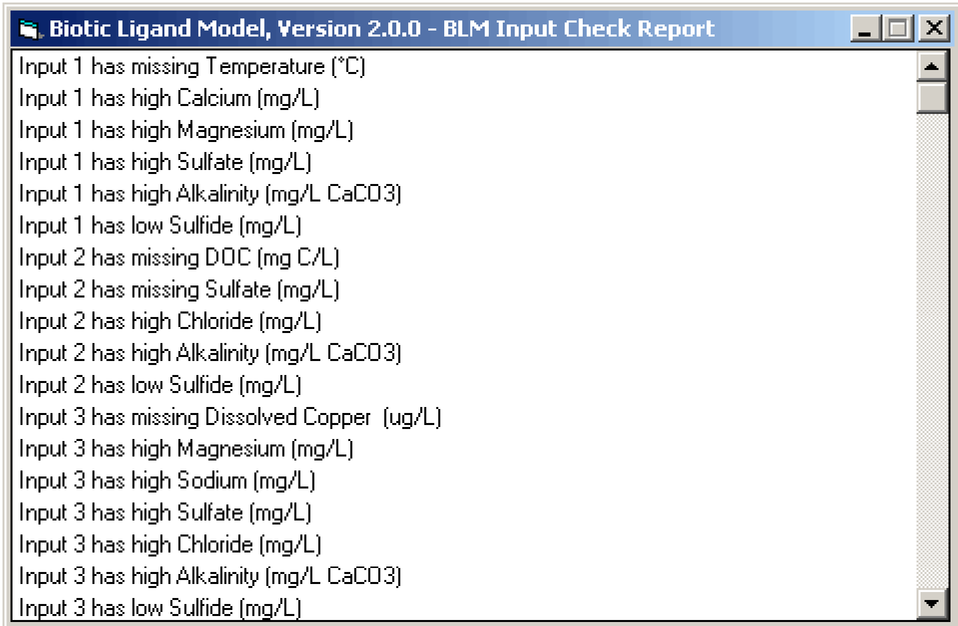

Figure 12: An Example of an Input Check Report Generated by the Check Inputs Function

Note that a similar check is also done every time the user edits the contents of any cell in the water chemistry input section. However, in this case an input check report is not generated. Instead, the out of range parameter value is highlighted in red as opposed to the normal text color of black.

6.4.6 Run BLM

This icon is used to launch the BLM program to predict either metal toxicity or speciation for the user-specified selections for the site water chemistry described in the BLM datafile currently open in the BLM Windows Interface. In case the BLM datafile has been edited since its last save, the user is queried for confirmation on whether to save the file and the BLM predictions proceed subsequently.

6.4.7 Help

This feature provides a point-and-click help functionality for several features of the interface application. To use this feature, simply click on this icon and point and click on the icon or area for which the user is interested in finding help/additional information.

6.5 Current Selection Display

This area of the interface window displays the current metal, organism, and prediction mode selections made by the user. For the example shown in Figure 2 the user has opted to predict the toxicity of copper to fathead minnows by using the "Shortcuts Menu" buttons Prediction Mode and Metal/Organism Selection. The options selected by the user are saved in the BLM datafile and the next time the user opens the BLM datafile the application defaults to the selections made by the user at the time of the previous file save.

6.6 EDITING CELL

This area shows the value of the parameter in the current cell as it is being edited.

6.7 DATAFILE DESCRIPTION

This area is provided for the user to insert comments describing the BLM datafile which will then be saved along with the water chemistry parameters input by the user. Though it is not of critical importance to the use of the BLM, for record keeping and possibly QA/QC purposes, it is a desirable input.

6.8 ITEM DESCRIPTION

Located at the very bottom of the interface window, this area is designed to show a brief description of the icon/image/area the mouse cursor is currently positioned over. For the case shown in Figure 2, the mouse cursor is positioned over the "Data Inputs" area. Similar messages are displayed when the mouse cursor is moved over other areas of the interface window.

6.9 DESCRIPTION OF OUTPUT FILES

When run in the metal speciation or metal toxicity mode, the BLM creates two output files within the directory containing the BLM input file. The names of the output files are based on the name of the input file. For example, using the input file "TEST.BLM" would create two output files, "TEST.SIM" (the simple version of the model output), and "TEST.DET" (the detailed version).

The detailed version of the model output contains all the chemical species in the simulation. Since this file can grow quite large, the more useful information is summarized in the simple version of output. The simple version of the model output contains the most relevant information for most users. Included are the site and sample labels, the mode of operation (i.e., did the BLM use an input dissolved metal concentration to predict metal speciation or was it predicting the LC50?), the pH, the total dissolved metal in mol/L (this is the input metal concentration in the speciation mode and the predicted LC50 in the toxicity prediction mode), the free metal concentration in mol/L, the activity-corrected free metal concentration in mol/L, concentration of metal bound to DOC in mol/L, concentration of metal and metal hydroxide bound to DOC in mol/L, the concentration of metal on the biotic ligand in nmol/g_{wet} of the gill, the DOC in mg/L, the percent humic acid and the rest of the input water chemistry in units of mol/L.

SECTION 7

INPUT CHECK RANGE

In order to provide users with an idea of the range of water chemistry to which the BLM can be applied, the range of parameter values to which the BLM has been developed and calibrated is defined in the BLM interface application. The users can check to verify if the user input water chemistry parameter values are within this range to which the BLM has been calibrated. This is done by using the “Check Inputs” function. The ranges prescribed for each of the BLM input parameters are shown below.

PARAMETER	LOWER BOUND	UPPER BOUND
Temperature (°C)	10	25
pH	4.9	9.2
DOC (mg/L)	0.05	29.65
Humic Acid Content (%)	10	60
Calcium (mg/L)	0.204	120.24
Magnesium (mg/L)	0.024	51.9
Sodium (mg/L)	0.16	236.9
Potassium (mg/L)	0.039	156
Sulfate (mg/L)	0.096	278.4
Chloride (mg/L)	0.32	279.72
Alkalinity (mg/L)	1.99	360
DIC (mmol/L)	0.056	44.92
Sulfide (mg/L)	0	

SECTION 8

EXAMPLE APPLICATION

The BLM Windows Interface installation also contains an example application for demonstration purposes. This file is named “Kansas River.BLM” and is installed along with the BLM interface application and is located in the “Data” directory within the BLM home directory on the user's hard-disk. The file can be opened directly, by double clicking on the file name through a file-system manager such as Microsoft Windows Explorer or by first starting the BLM Windows Interface application and selecting the file through the “File -----> Open” action. This example datafile contains the water quality observations for USGS Station 6892350 on the Kansas River at Desoto, KS. Although in this case, only observations with a complete characterization of all the BLM input parameters are included in the BLM datafile, it is recommended that all the available water quality measurements (including the ones without a complete characterization of the BLM input parameters) be included in the BLM datafile.

This datafile “Kansas River.BLM” can be used to predict metal speciation using the input metal concentrations or to predict the LC50 to a variety of metals and organisms. However, it is recommended that separate BLM datafiles be maintained for each metal. In this case, the datafile contains dissolved copper concentrations and the BLM can be used to predict the inorganic, organic, and biotic speciation by setting the BLM prediction mode to “Speciation” using the Shortcut Menu button Prediction Mode. Metal toxicity for the specified site water chemistry can also be predicted by setting the prediction mode to “Toxicity” and selecting the metal and organism for which toxicity is to be predicted.

SECTION 9

CONTACT INFORMATION

For questions or problems, including bug reports, relating to the use and application of the Biotic Ligand Model or the BLM Windows Interface, please contact either:

Cindy Roberts
U.S. EPA
1200 Pennsylvania Ave, NW (MC4304T)
Washington, DC 20460
roberts.cindy@epa.gov

or

Additional information including support details can be found online at http://www.hydroqual.com/blm.

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Appendix C. Other Data on Effects of Copper on Freshwater and Saltwater Organisms

Appendix C1. 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% dow 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

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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
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

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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
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

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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
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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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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Species	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

Appendix C1. 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
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

Appendix C1. 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, *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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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Rainbow trout (2.88 g), *Oncorhynchus mykiss*	F,M,T	Copper chloride	9.2	168 hr	LC50	36.7	-	Cusimano et al. 1986
Rainbow trout (2.70 g), *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

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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 (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

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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 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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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Guppy (2.3-2.8 cm; male), *Poecilia reticulata*	R,U	Copper sulfate	144-188	96 hr	LC50	210		Deshmukh and Marathe 1980
Guppy (340 mg; female), *Poecilia reticulata*	R,U	Copper sulfate	144-188	96 hr	LC50	480		Deshmukh and Marathe 1980
Guppy (1.5 cm), *Poecilia reticulata*	R,U	Copper sulfate	260	48 hr	LC50	2,500	-	Khangarot et al. 1981a
Guppy (1.5 cm), *Poecilia reticulata*	R, U	Copper sulfate	181	96 hr	LC50	986	-	Khangarot and Ray 1987b
Guppy (1 mo), *Poecilia reticulata*	F,U	Copper sulfate	76	24 hr	LC50	1,370	-	Minicucci 1971
Guppy (1 mo), *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

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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
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

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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
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 C1. 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
Johnny darter, *Etheostoma nigrum*	S,M,T	Copper sulfate	170	96 hr	Lowered critical thermal maximum	148	-	Lydy and Wissing 1988
Johnny darter, *Etheostoma nigrum*	F,M,T,D	Copper sulfate	316	96 hr	LC50 (high BOD)	6,800	-	Geckler et al. 1976
Orangethroat darter, *Etheostoma spectabile*	F,M,T,D	Copper sulfate	314	96 hr	LC50 (high BOD)	7,100	-	Geckler et al. 1976
Orangethroat darter, *Etheostoma spectabile*	F,M,T,D	Copper sulfate	303	96 hr	LC50 (high BOD)	9,800	-	Geckler et al. 1976
Orangethroat darter, *Etheostoma spectabile*	F,M,T,D	Copper sulfate	318	96 hr	LC50 (high BOD)	7,900	-	Geckler et al. 1976
Orangethroat darter, *Etheostoma spectabile*	F,M,T,D	Copper sulfate	316	96 hr	LC50 (high BOD)	5,500	-	Geckler et al. 1976
Orangethroat darter, *Etheostoma spectabile*	F,M,T,D	Copper sulfate	274	96 hr	LC50 (high BOD)	5,800	-	Geckler et al. 1976
Orangethroat darter (4.4 cm), *Etheostoma spectabile*	F,M,T,D	Copper sulfate	314	96 hr	LC50 (high BOD)	7,100	-	Geckler et al. 1976
Orangethroat darter (4.4 cm), *Etheostoma spectabile*	F,M,T,D	Copper sulfate	303	96 hr	LC50 (high BOD)	9,400	-	Geckler et al. 1976
Mozambique tilapia (8.7 cm), *Tiliapia mossambica*	S,U	Copper sulfate	115	96 hr	LC50	1,500		Qureshi and Saksema 1980
Leopard frog (embryo), *Rana pipiens*	R,U	Copper sulfate	100	8 days	EC50 (death and deformity)	50	-	Birge and Black 1979
Wood frog (larva), *Rana sylvatica*	S,U	Copper chloride	6.2	28 days	100% mortality	15	-	Horne and Dunson 1995
Wood frog (larva), *Rana sylvatica*	S,U	Copper chloride	12.4	28 days	Little effect	15	-	Horne and Dunson 1995
Wood frog (larva), *Rana sylvatica*	S,U	Copper chloride	6.2	28 days	Little effect	15	-	Horne and Dunson 1995
Wood frog (larva), *Rana sylvatica*	S,U	Copper chloride	12.4	28 days	Little effect	15	-	Horne and Dunson 1995
Narrow-mouthed toad (embryo), *Gastrophryne carolinensis*	R,U	Copper sulfate	195	7 days	EC50 (death and deformity)	40	-	Birge 1978; Birge and Black 1979
American toad, *Bufo americanus*	F,M,T	Copper sulfate	112.4	80 min	Avoidance threshold	100	-	Black and Birge 1980
Fowler's toad (embryo), *Bufo fowleri*	R,U	Copper sulfate	195	7 days	LC50	40	-	Birge and Black 1979
Fowler's toad (embryo), *Bufo fowleri*	R,U	Copper sulfate	195	7 min	EC50 (death and deformity)	26,960	-	Birge and Black 1979
Southern gray treefrog (embrsyo), *Hyla chrysoscelis*	R,U	Copper sulfate	195	7 min	EC50 (death and deformity)	40	-	Birge and Black 1979
Marbled salamander (embryo), *Ambysoma opacum*	R,U	Copper sulfate	195	8 days	EC50 (death and deformity)	770	-	Birge et al. 1978; Birge and Black 1979
Jefferson salamander (larva), *Ambyostoma jeffersonianum*	S,U	Copper chloride	6.2	7 days	LC100	15	-	Horne and Dunson 1995

Appendix C1. 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
Jefferson salamander (larva), *Ambyostoma jeffersonianum*	S,U	Copper chloride	12.4	28 days	LC100	15	-	Horne and Dunson 1995
Jefferson salamander (embryo), *Ambyostoma jeffersonianum*	S,M,D	Copper chloride	6.5	96 hr	LC50	328.1	-	Horne and Dunson 1994
Two-lined Salamander, *Eurycea bislineata*	S,M,T	-	100-120	48 hr	LC50	1,120	-	Dobbs et al. 1994

a S = static; R = renewal; F = flow-through; M = measured; U = unmeasured; T = total metal concentration measured; D = dissolved metal concentration; I = ionic

b Results are expressed as copper, not as the chemical

c In river water

Appendix C2. Other Data on Effects of Copper on Saltwater Organisms

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Natural phytoplankton populations	-	-	-	5 days	Reduced chlorophyll a	19	-	Hollibaugh et al. 1980
Natural phytoplankton populations	-	-	-	4 days	Reduced biomass	6.4	-	Hollibaugh et al. 1980
Dinoflagellate, *Glenodinium halli*	S,U	-	28	48 hr	No growth	10-160	-	Wilson and Freeberg 1980
Dinoflagellate, *Glenodinium halli*	S,U	-	28	48 hr	No effect on growth	2-120	-	Wilson and Freeberg 1980
Dinoflagellate, *Gymnodinium splendens*	S,U	-	28	48 hr	No growth	10-100	-	Wilson and Freeberg 1980
Dinoflagellate, *Gymnodinium splendens*	S,U	-	28	48 hr	No effect on growth	5-90	-	Wilson and Freeberg 1980
Phytoflagellate, *Isochrysis galbana*	S,U	-	28	48 hr	No growth	100-1,000	-	Wilson and Freeberg 1980
Phytoflagellate, *Isochrysis galbana*	S,U	-	28	48 hr	No effect on growth	20-300	-	Wilson and Freeberg 1980
Alga, *Laminaria hyperboria*	-	-	-	28 days	Growth decrease	50	-	Hopkins and Kain 1971
Diatom, *Asterionella japonica*	S,U	Copper sulfate	-	72 hr	EC50 (growth)	12.7	-	Fisher and Jones 1981
Diatom, *Thalassiosira pseudonana*	S,U	Copper chloride	30-34	72 hr	EC50 (growth rate)	6	-	Erickson 1972
Diatom, *Thalassiosira pseudonana*	S,U	-	28	48 hr	No growth	80-500	-	Wilson and Freeberg 1980
Diatom, *Thalassiosira pseudonana*	S,U	-	28	48 hr	No effect on growth	50-70	-	Wilson and Freeberg 1980
Red alga (gametophytes), *Ceramium strictum*	S,U	-	34	24 hr	EC50 (fertilization)	10-15	-	Eklund 1993
Red alga (mature), *Champia parvula*	S,U	-	30	48 hr	LOEC (reproduction)	2.0	-	U.S. EPA 1988
Red alga (mature), *Champia parvula*	S,U	Copper sulfate	30	48 hr	IC50 (fertilization)	1.4	-	Morrison et al. 1989
Red alga (female), *Chondrus crispus*		Copper sulfate	-	24 hr	14% reduction in growth	10	-	Staples et al. 1995
Bladderwrack (zygotes), *Fucus vesiculosis*	S,U	-	6	24 hr	EC50 (germination)	60	-	Andersson and Kautsky 1996
Kelp (mature sporophyte), *Laminaria saccharina*	S,U	Copper sulfate	-	1 hr	LOEC (28% decrease is meiospore release)	50	-	Chung and Brinkhuis 1986
Giant kelp (spores), *Macrocystis pyrifera*	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	<40.8	-	Anderson et al. 1990
Giant kelp (spores), *Macrocystis pyrifera*	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	99.1	-	Anderson et al. 1990
Giant kelp (spores), *Macrocystis pyrifera*	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	19.4	-	Anderson et al. 1990

Appendix C2. Other Data on Effects of Copper on Saltwater Organisms

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Giant kelp (spores), *Macrocystis pyrifera*	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	54.1	-	Anderson et al. 1990
Giant kelp (spores), *Macrocystis pyrifera*	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	55.8	-	Anderson et al. 1990
Giant kelp (spores), *Macrocystis pyrifera*	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	94.5	-	Anderson et al. 1990
Giant kelp (spores), *Macrocystis pyrifera*	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	50.1	-	Anderson et al. 1990
Giant kelp (spores), *Macrocystis pyrifera*	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	<40.8	-	Anderson et al. 1990
Giant kelp (spores), *Macrocystis pyrifera*	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	<40.8	-	Anderson et al. 1990
Giant kelp (spores), *Macrocystis pyrifera*	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	<31.1	-	Anderson et al. 1990
Giant kelp (spores), *Macrocystis pyrifera*	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	<10.1	-	Anderson et al. 1990
Giant kelp (spores), *Macrocystis pyrifera*	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	18.8	-	Anderson et al. 1990
Giant kelp (spores), *Macrocystis pyrifera*	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	8.8	-	Anderson et al. 1990
Giant kelp (spores), *Macrocystis pyrifera*	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	9.3	-	Anderson et al. 1990
Giant kelp (spores), *Macrocystis pyrifera*	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	10.2	-	Anderson et al. 1990
Giant kelp, *Macrocystis pyrifera*	R,M,T	Copper chloride	33-35	42 hr	NOEC (Spore germination)	20	-	Garman et al. 1994
Giant kelp, *Macrocystis pyrifera*	R,M,T	Copper chloride	33-35	42 hr	LOEC (Spore germination)	40	-	Garman et al. 1994
Giant kelp, *Macrocystis pyrifera*	R,M,T	Copper chloride	33-35	42 hr	NOEC (Germ tube growth)	20	-	Garman et al. 1994
Giant kelp, *Macrocystis pyrifera*	R,M,T	Copper chloride	33-35	42 hr	NOEC (Germ tube growth)	40	-	Garman et al. 1994
Giant kelp, *Macrocystis pyrifera*	R,M,T	Copper chloride	33-35	42 hr	NOEC (Nuclear migration)	10	-	Garman et al. 1994
Giant kelp, *Macrocystis pyrifera*	R,M,T	Copper chloride	33-35	42 hr	NOEC (Nuclear migration)	20	-	Garman et al. 1994
Hydroid, *Campanularia flexuosa*	S,U	Copper chloride	FSW	11 days	Threshold reduced growth rate	13	-	Stebbing 1976
Hydroid, *Campanularia flexuosa*	S,U	Copper chloride	FSW	11 days	Glucosamidase increased	1.43	-	Moore and Stebbing 1976
Hydromedusa, *Phialidium* sp.	S,U	-	-	24 hr	LC50	36	-	Reeve et al. 1976
Ctenophore, *Pleurobrachia plicatilis*	S,U	-	-	24 hr	LC50	33	-	Reeve et al. 1976

Appendix C2. Other Data on Effects of Copper on Saltwater Organisms

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Ctenophore, *Mnemiopsis mccradyi*	S,U	-	-	24 hr	LC50	17-29	-	Reeve et al. 1976
Rotifer, *Brachionus plicatilis*	S,U	-	-	24 hr	LC50	100	-	Reeve et al. 1976
Rotifer (<3 hr), *Brachionus plicatilis*	S, U	Copper sulfate	15	24 hr	LC50	120	-	Snell and Persoone 1989a
Rotifer (<3 hr), *Brachionus plicatilis*	S, U	Copper sulfate	30	24 hr	LC50	130	-	Snell and Persoone 1989a
Rotifer (<3 hr), *Brachionus plicatilis*	S,U	-	15	24 hr	LC50	63	-	Snell et al. 1991a
Rotifer (<3 hr), *Brachionus plicatilis*	S,U	-	15	24 hr	LC50	35	-	Snell et al. 1991a
Rotifer (<3 hr), *Brachionus plicatilis*	S,U	-	15	24 hr	LC50	170	-	Snell et al. 1991a
Rotifer (<5 hr), *Brachionus plicatilis*	S,U	Copper chloride	15	1 hr	NOEC (ingestion)	100	-	Juchelka and Snell 1995
Polychaete worm (embryos), *Hediste diversicolor*	R,U	Copper nitrate	14.6	6 days	Severe reduction in hatching	100	-	Ozoh and Jones 1990a
Polychaete worm (embryos), *Hediste diversicolor*	R,U	Copper nitrate	21.9	6 days	Severe reduction in hatching	100	-	Ozoh and Jones 1990a
Polychaete worm (embryos), *Hediste diversicolor*	R,U	Copper nitrate	29.2	6 days	Severe reduction in hatching	100	-	Ozoh and Jones 1990a
Polychaete worm, *Phyllodoce maculata*	R,U	Copper sulfate	-	9 days	LC50	80	-	McLusky and Phillips 1975
Polychaete worm, *Neanthes arenaceodentata*	F,M,T	Copper nitrate	31	28 days	LC50	44	-	Pesch and Morgan 1978
Polychaete worm, *Neanthes arenaceodentata*	F,M,T	Copper nitrate	31	28 days	LC50	100	-	Pesch and Morgan 1978
Polychaete worm, *Neanthes arenaceodentata*	F,M,T	Copper nitrate	31	7 days	LC50	137	-	Pesch and Hoffman 1982
Polychaete worm, *Neanthes arenaceodentata*	F,M,T	Copper nitrate	31	10 days	LC50	98	-	Pesch and Hoffman 1982
Polychaete worm, *Neanthes arenaceodentata*	F,M,T	Copper nitrate	31	28 days	LC50	56	-	Pesch and Hoffman 1982
Polychaete worm (21-day), *Neanthes arenaceodentata*	F,M,T	Copper chloride	29	28 days	LC50	83	-	Pesch et al. 1986
Polychaete worm (21-day), *Neanthes arenaceodentata*	F,M,T	Copper chloride	29	28 days	LC50	81	-	Pesch et al. 1986
Polychaete worm (21-day), *Neanthes arenaceodentata*	F,M,T	Copper chloride	29	28 days	LC50	86	-	Pesch et al. 1986
Polychaete worm, *Ophrytrocha diadema*	S,U	Copper chloride	FSW 98%	48 hr	LC50	100-330	-	Parker 1984
Polychaete worm, *Ophrytrocha diadema*	S,U	Copper chloride	FSW 98%	48 hr	LC50	60-80	-	Parker 1984

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Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Polychaete worm, *Ophrytrocha diadema*	S,U	Copper chloride	FSW 98%	48 hr	LC50	80-100	-	Parker 1984
Polychaete worm, *Ophrytrocha diadema*	S,U	Copper chloride	FSW 98%	48 hr	LC50	80-110	-	Parker 1984
Polychaete worm, *Cirriformia spirabranchia*	R,U	Copper sulfate	29	26 days	LC50	40	-	Milanovich et al. 1976
Annelids (larvae), mixed species	S,U	-	-	24 hr	LC50	89	-	Reeve et al. 1976
Black abalone. *Haliotis cracherodii*	-	-	-	96 hr	Histopathological gill abnormalities	>32	-	Martin et al. 1977
Red abalone. *Haliotis rufescens*	-	-	-	96 hr	Histopathological gill abnormalities	>32	-	Martin et al. 1977
Coral (embryos), *Montastraea faveolata*	S,U	Copper sulfate	36.0	24 hr	EC50 (normal development)	24.9	-	Rumbold and Snedaker 1997
Channeled whelk, *Busycon canaliculatum*	R,U	Copper chloride	-	77 days	LC50	470	-	Betzer and Yevich 1975
Mudsnail, *Nassarius obsoletus*	-	-	-	72 hr	Decrease in oxygen consumption	100	-	MacInnes and Thurberg 1973
Mudsnail (embryo), *Ilyanassa obsoleta*	S,U	Copper chloride	-	ca. 3 hr	Abnormal development	63.5	-	Conrad 1988
Queen conch (embryo), *Strombus gigas*	S,U	Copper sulfate	36.8	24 hr	EC50 (normal development)	21.3	-	Rumbold and Snedaker 1997
Bivalve mollusk (embryo), Isognomon californicum	S, U	Copper chloride	16	96 hr	LC50	7		Ringwood 1992
Blue mussel (1-2 cm), *Mytilus edulis*	S,U	Copper chloride	-	7 days	LC50	100-200	-	Scott and Major 1972
Blue mussel (ca, 2 cm), *Mytilus edulis*	R,U	Copper sulfate	16.5	7 days	LC50	200	-	Huilsom 1983
Blue mussel (ca, 2 cm), *Mytilus edulis*	R,U	Copper sulfate	16.5	14 days	LC50	100	-	Huilsom 1983
Blue mussel (1.0-1.5 cm), *Mytilus edulis*	F,M,T	Copper chloride	-	10 days	EC50 (growth)	6	-	Redpath 1985
Blue mussel (0.5-1.5 cm), *Mytilus edulis*	S,U	Copper sulfate	brackish	24 hr	LC50 (after 3 weeks)	420	-	Sunila and Lindstrom 1985
Blue mussel (2.0-3.0 cm), *Mytilus edulis*	S,U	Copper sulfate	brackish	24 hr	LC50 (after 3 weeks)	270	-	Sunila and Lindstrom 1985
Blue mussel (1-1.9 cm), *Mytilus edulis*	F,U	Copper sulfate	32.1	144 hr	EC20 (growth rate)	3	-	Stromgren 1986
Blue mussel (2-3.5 cm), *Mytilus edulis*	S,U	Copper sulfate	-	24 hr	Gill histopathology 1 yr later	100	-	Sunila 1986
Blue mussel (2-3.5 cm), *Mytilus edulis*	S,U	Copper sulfate	-	24 hr	Renal cysts 4 months later	200	-	Sunila 1989
Blue mussel (larvae), *Mytilus edulis*	R,U	Copper chloride	32	15 days	LC50	270	-	Beaumont et al. 1987

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Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Blue mussel (5-6 cm), *Mytilus edulis*	S,U	-	-	5 days	EC50 (filtration rate)	2	-	Grace and Gainey 1987
Blue mussel (5-6 cm), *Mytilus edulis*	S,U	-	-	96 hr	EC50 (heart rate)	170	-	Grace and Gainey 1987
Blue mussel (49.5 mm), *Mytilus edulis*	F,U	Copper chloride	26	126 days	Significant increase in mortality	5	-	Nelson et al. 1988
Blue mussel (4-6 cm), *Mytilus edulis*	F,M,T	Copper chloride	35	Several hr	Halted pumping	20.8-25.6	-	Redpath and Davenport 1988
Blue mussel (7-9 cm), *Mytilus edulis*	R,U	Copper sulfate	32	20 days	LC100	150	-	Hawkins et al. 1989
Blue mussel (4.76 cm), *Mytilus edulis*	F,U	Copper sulfate	30	7 days	LOEC (scope for growth)	32	-	Sanders et al. 1991
Blue mussel (maturing), *Mytilus edulis*	R,M,T	Copper sulfate	32	1 mo	IC50 (no. spawning w/ KCl injection)	3.3	-	Stromgren and Nielsen 1991
Blue mussel (150 um), *Mytilus edulis*	R,M,T	Copper sulfate	32	10 days	EC50 (growth)	5	-	Stromgren and Nielsen 1991
Blue mussel (5.7 cm), *Mytilus edulis*	R,U	Copper chloride	36	9 days	LC50	894	-	Weber et al. 1992
Blue mussel (5.7 cm), *Mytilus edulis*	R,U	Copper chloride	36	14 days	LC50	146	-	Weber et al. 1992
Blue mussel (embryo), *Mytilus edulis*	S,U	Copper chloride	FSW	3 days	23% fewer normal larvae	10	-	Hoare et al. 1995a
Blue mussel (embryo), *Mytilus edulis*	S,U	Copper chloride	FSW	3 days	49% fewer normal larvae	10	-	Hoare et al. 1995a
Blue mussel (embryo), *Mytilus edulis*	S,U	Copper chloride	FSW	3 days	80% fewer survivors after 5 mo	10	-	Hoare et al. 1995b
Bay scallop, *Argopecten irradians*	F,M,T	Copper chloride	27.4-31.5	42 days	EC50 (growth)	5.8	-	Pesch et al. 1979
Bay scallop, *Argopecten irradians*	F,M,T	Copper chloride	29-32	119 days	100% mortality	5	-	Zaroogian and Johnson 1983
Bay scallop (31.2 mm), *Argopecten irradians*	F,U	Copper chloride	26	126 days	Significant increase in mortality	5	-	Nelson et al. 1988
Giant sea scallop (107 mm ht.), *Placopectin magellanicus*	F,M	Copper sulfate	24.7	8 wk	Significant decrease in gonad weight, protein, RNA	20	-	Gould et al. 1988
Bivalve mollusk (sperm), *Isognomen californicum*	S,U	Copper chloride	16	1 hr	EC50 (fertilization)	55	-	Ringwood 1992
Eastern oyster (larva), *Crassostrea virginica*	S,U	Copper chloride	25	12 days	LC50	46	-	Calabrese et al. 1977
Eastern oyster (embryo), *Crassostrea virginica*	S,U	Copper chloride	25	-	LC50	128	-	Calabrese et al. 1973
Pearl oyster (embryos), *Pteria colymbus*	S,U	Copper sulfate	36.6	24 hr	EC50 (normal development)	<7	-	Rumbold and Snedaker 1997
Common rangia, *Rangia cuneata*	S,U	-	<1.0	96 hr	LC50	210	-	Olson and Harrel 1973

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Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Surf clam (30.4 mm), *Spisula solidissima*	F,U	Copper chloride	26	126 days	Significant increase in mortality	5	-	Nelson et al. 1988
Clam, *Macoma inquinata*	F,U	Copper sulfate	-	30 days	LC50	15.7	-	Crecelius et al. 1982
Clam, *Macoma inquinata*	F,U	Copper sulfate	-	30 days	LC50	20.7	-	Crecelius et al. 1982
Quahog clam (larva), *Mercenaria mercenaria*	R,U	Copper chloride	24	8-10 days	LC50	30	-	Calabrese et al. 1977
Quahog clam, *Mercenaria mercenaria*	F,M,T	-	31	11-15 wk	LC50	25	-	Shuster and Pringle 1968
Common Pacific littleneck, *Protothaca staminea*	-	-	-	17 days	LC50	39	-	Roesijadi 1980
Soft-shell clam (3.9-4.9 cm), *Mya arenaria*	S,U	Copper chloride	30	7 days	LC50	35	-	Eisler 1977
Horseshoe crab (embryo), *Limulus polyphemus*	R,U	Copper sulfate	20	72 hr	LC50	2,000	-	Botton et al. 1998
Horseshoe crab (embryo), *Limulus polyphemus*	R,U	Copper sulfate	20	72 hr	LC50	171,000	-	Botton et al. 1998
Horseshoe crab (blastula and gastrula stage embryo), *Limulus polyphemus*	R,U	Copper sulfate	-	24 hr	Total mortality	100,000	-	Itow et al. 1998
Horseshoe crab (post-gastrula embryo), *Limulus polyphemus*	R,U	Copper sulfate	-	24 hr	<50% mortality	100,000	-	Itow et al. 1998
Copepod, *Enidula vulgaris*	S,U	-	-	24 hr	LC50	192	-	Reeve et al. 1976
Copepod, *Euchaeta marina*	S,U	-	-	24 hr	LC50	188	-	Reeve et al. 1976
Copepod, *Metridia pacifica*	S,U	-	-	24 hr	LC50	176	-	Reeve et al. 1976
Copepod (24 hr), *Eurytemora affinis*	R,M,T	Copper in HNO_3	FSW	96 hr	LOEC (development)	27.2	-	Sullivan et al. 1983
Copepod (24 hr), *Eurytemora affinis*	R,M,T	Copper in HNO_3	FSW	96 hr	LOEC (development)	23.5	-	Sullivan et al. 1983
Copepod (24 hr), *Eurytemora affinis*	S,M,D	Copper chloride	14-16	8 days	LOEC (survival, gravid females, maturation)	-	79.9[c]	Hall et al. 1997
Copepod *Labidocera scotti*	S,U	-	-	24 hr	LC50	132	-	Reeve et al. 1976
Copepod, *Acartia clausi*	S,U	Copper sulfate	FSW	48 hr	LC50	34	-	Moraitou-Apostolopoulou 1978
Copepod, *Acartia clausi*	S,U	Copper sulfate	FSW	96 hr	LC50	<10	-	Moraitou-Apostolopoulou 1978
Copepod, *Acartia tonsa*	F,U	Copper nitrate	30	6 days	LC50	9-78	-	Sosnowski et al. 1979
Copepod, *Acartia tonsa*	-	-	-	24 hr	LC50	104-311	-	Reeve et al. 1976

Appendix C2. Other Data on Effects of Copper on Saltwater Organisms

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Copepod, *Acartia tonsa*	R,U	Copper sulfate	38	10 days	Decrease mean lifespan by about 40%	1	-	Verriopoulous 1992
Copepod (adult female), *Tisbe holothuriae*	S,U	-	FSW	48 hr	LC50	80	-	Moraitou-Apostolopoulou and Verriopoulos 1982
Copepod (nauplii), mixed species	S,U	-	-	24 hr	LC50	90	-	Reeve et al. 1976
Barnacle (nauplii), *Balanus amphitrite*	S,U	Copper chloride	FSW	22-24 hr	LC50	480	-	Sasikumar et al. 1995
Barnacle (3 hr nauplii), *Balanus improvisus*	S,M,T	Copper oxide	FSW	96 hr	LC50	20	-	Koryakova and Korn 1993
Mysid shrimp, *Americamysis bahia*	S,U	Copper chloride	20	48 hr	LC50	-	423	PBS&J 1999
Mysid shrimp, *Americamysis bahia*	S,U	Copper chloride	20	48 hr	LC50	-	284	PBS&J 1999
Mysid shrimp, *Americamysis bahia*	S,U	Copper chloride	20	48 hr	LC50	-	403	PBS&J 1999
Mysid shrimp, *Americamysis bahia*	S,U	Copper chloride	20	48 hr	LC50	-	367	PBS&J 1999
Mysid (7-day), *Americamysis bahia*	R,U	Copper sulfate	20-30	7 days	LC50	169.3	-	Morrison et al. 1989
Mysid shrimp, *Americamysis bahia*	R, M, D	Copper chloride	30	96 hr	LC50	-	164	SAIC 1993
Mysid, *Mysidopsis bahia*	LC	-	30	-	Reduction in reproduction	54.1	44.9	Lussier et al. 1985
Amphipod, *Ampelisca abdita*	F	Copper nitrate	30	7 days	LC50	86.8	-	Scott et al. Manuscript
Euphausiid, *Euphausia pacifica*	S,U	-	-	24 hr	LC50	14-30	-	Reeve et al. 1976
Pink shrimp (3-5 day post-larvae), *Penaeus duorarum*	S,U	Copper chloride	25	96 hr	LC50	832	-	Cripe 1994
Grass shrimp, *Palaemonetes pugio*	S,M	Copper acetate	25	96 hr	LC50	12,600	-	Curtis et al. 1979; Curtis and Ward 1981
Grass shrimp, *Palaemonetes pugio*	S,M,T	Copper acetate	25	96 hr	LC50	35,900	-	Curtis et al. 1979
Grass shrimp (<20 mm), *Palaemonetes pugio*	S,M,T	Copper sulfate	8-12	48 hr	LC50	2,100	-	Burton and Fisher 1990
Coon stripe shrimp, *Pandalus danae*	F,U	Copper sulfate	-	30 days	LC50	27.0	-	Crecelius et al. 1982
Pink shrimp, *Pandalus montagui*	R,M,T	Copper chloride	-	7 days	LC50	50	-	McLeese and Ray 1986
Sand shrimp, *Crangon septemspinosa*	R,M,T	Copper chloride	-	7 days	LC50	1,400	-	McLeese and Ray 1986
American lobster (450 g adult), *Homarus americanus*	F,M,T	Copper sulfate	30	96 hr	LC50	100	-	McLeese 1974

Appendix C2. Other Data on Effects of Copper on Saltwater Organisms

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
American lobster, *Homerus americanus*	F,M,T	Copper sulfate	30	13 days	LC50	56	-	McLeese 1974
Yellow crab (embryo), *Cancer anthonyi*	R,U	Copper chloride	34	7 days	LC50	7,080	-	Macdonald et al. 1988
Yellow crab (embryo), *Cancer anthonyi*	R,U	Copper chloride	34	7 days	28% reduction in hatching	10	-	Macdonald et al. 1988
Sea urchin (sperm), *Arbacia punctulata*	S,U	Copper chloride	FSW	12 min	42% decrease in sperm motility	318	-	Young and Nelson 1974
Sea urchin (embryo), *Arbacia punctulata*	S,U	Copper sulfate	30	4 hr	EC50 (growth as thymidine incorporation)	14	-	Nacci et al. 1986
Sea urchin (sperm), *Arbacia punctulata*	S,U	Copper sulfate	30	1 hr	EC50 (fertilization)	12	-	Nacci et al. 1986
Sea urchin (sperm), *Arbacia punctulata*	S,U	-	30	1 hr	EC50 (fertilization)	7.3	-	Neiheisel and Young 1992
Sea urchin (sperm), *Arbacia punctulata*	S,U	-	30	1 hr	EC50 (fertilization)	20.9	-	Neiheisel and Young 1992
Sea urchin (sperm), *Arbacia punctulata*	S,U	-	30	1 hr	EC50 (fertilization)	11.9	-	Neiheisel and Young 1992
Sea urchin (sperm), *Arbacia punctulata*	S,U	-	30	1 hr	EC50 (fertilization)	19.3	-	Neiheisel and Young 1992
Sea urchin (sperm), *Arbacia punctulata*	S,U	-	30	1 hr	EC50 (fertilization)	79.2	-	Neiheisel and Young 1992
Sea urchin (sperm), *Arbacia punctulata*	S,U	Copper sulfate	30	1 hr	EC50 (fertilization)	33.3	-	Morrison et al. 1989
Rock-boring urchin (embryo), *Echinometra lucunter*	S,U	Copper sulfate	36	24 hr	EC50 (normal development)	21.9	-	Rumbold and Snedaker 1997
Sea urchin (sperm), *Echinometra mathaei*	S,U	Copper chloride	FSW	1 hr	EC50 (fertilization)	14	-	Ringwood 1992
Variegated urchin (embryo), *Lytechinus variegatus*	S,U	Copper sulfate	35.7	24 hr	EC50 (normal development)	33.8	-	Rumbold and Snedaker 1997
Green sea urchin (sperm), *Strongylocentrotus droebachiensis*	S,M,T	Copper chloride	30	1 hr	EC50 (fertilization)	59	-	Dinnel et al. 1989
Green sea urchin (embryo), *Strongylocentrotus droebachiensis*	S,M,T	Copper chloride	30	120 hr	EC50 (development)	21	-	Dinnel et al. 1989
Red sea urchin (sperm), *Strongylocentrotus franciscanus*	S,M,T	Copper chloride	30	1 hr	EC50 (fertilization)	1.9	-	Dinnel et al. 1989
Sea urchin (sperm), *Strongylocentrotus purpuratus*	S,M,T	Copper chloride	30	1 hr	EC50 (fertilization)	25	-	Dinnel et al. 1989
Sea urchin (embryo), *Strongylocentrotus purpuratus*	S,M,T	Copper chloride	30	120 hr	EC50 (development)	6.3	-	Dinnel et al. 1989
Sea urchin (sperm), *Strongylocentrotus purpuratus*	S,U	Copper sulfate	30	20 min	LOEC (fertilization)	40	-	Bailey et al. 1995
Sea urchin (sperm), *Strongylocentrotus purpuratus*	S,U	Copper sulfate	30	20 min	LOEC (fertilization)	39.4	-	Bailey et al. 1995

Appendix C2. Other Data on Effects of Copper on Saltwater Organisms

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Sand dollar (sperm), *Dendraster excentricus*	S,M,T	Copper chloride	30	1 hr	EC50 (fertilization)	26	-	Dinnel et al. 1989
Sand dollar (embryo), *Dendraster excentricus*	S,M,T	Copper chloride	31	72 hr	EC50 (development)	33	-	Dinnel et al. 1989
Sand dollar (sperm), *Dendraster excentricus*	S,U	Copper sulfate	30	20 min	LOEC (fertilization)	20	-	Bailey et al. 1995
Sand dollar (sperm), *Dendraster excentricus*	S,U	Copper sulfate	30	20 min	LOEC (fertilization)	26.2	-	Bailey et al. 1995
Sand dollar (sperm), *Dendraster excentricus*	S,U	Copper sulfate	30	20 min	LOEC (fertilization)	10.8	-	Bailey et al. 1995
Sand dollar (sperm), *Dendraster excentricus*	S,U	Copper sulfate	30	20 min	LOEC (fertilization)	7.6	-	Bailey et al. 1995
Sand dollar (sperm), *Dendraster excentricus*	S,U	Copper sulfate	30	20 min	LOEC (fertilization)	16	-	Bailey et al. 1995
Arrow worm, *Sagita hispida*	S,U	-	-	24 hr	LC50	43-460	-	Reeve et al. 1976
Atlantic menhaden, *Brevoortia tyrannus*	F,-	-	-	14 days	LC50	610	-	Engel et al. 1976
Atlantic herring (embryo), *Clupea harengus*	R,U	Copper sulfate	20	15 days	brain cell size reduced, perinuclear space increased	30	-	Abbasi et al. 1995
Atlantic herring (embryo), *Clupea harengus*	R,U	Copper sulfate	20	-	spinal deformities	50	-	Abbasi and Sheckley 1995
Pacific herring (1 hr larva), *Clupea harengus pailasi*	F,M,T	Copper chloride	-	6 days	LC50	33	-	Rice and Harrison 1978
Pacific herring (12 hr embryo), *Clupea harengus pailasi*	F,M,T	Copper chloride	-	6 days	LC50	900	-	Rice and Harrison 1978
Northern Anchovy (8-10 hr embryo), *Engraulis mordax*	F,M,T,I	-	SW	25 hr	LC50	186	-	Rice and Harrison 1979
Pink salmon (4.1 cm), *Oncorhynchus gorbuscha*	S,U	Copper nitrate	16.6	5 days	LC50	563	-	Holland et al. 1960
Hardhead catfish (26-29 cm), *Arius felis*	S,U	Copper chloride	30-32	72 hr	hyperactivity	100	-	Steele 1985
Hardhead catfish (26-29 cm), *Arius felis*	S,U	Copper chloride	30-32	72 hr	7-day latent hypoactivity	100	-	Steele 1985
Hardhead catfish (26-29 cm), *Arius felis*	S,U	Copper chloride	30-32	72 hr	57% mortality after 3 weeks	100	-	Steele 1985
Atlantic cod (embryo), *Gadus morhua*	-	-	-	14 days	LC50	10	-	Swedmark and Granmo 1981
Sheepshead minnow (<24 hr), *Cyprinodon variegatus*	R,M,T	Copper chloride or sulfate	30	7 days	Chronic value (survival)	253	-	Hughes et al. 1989
Sheepshead minnow (<24 hr), *Cyprinodon variegatus*	R,M,T	Copper chloride or sulfate	30	7 days	Chronic value (growth and survival)	177	-	Hughes et al. 1989
Sheepshead minnow (<24 hr), *Cyprinodon variegatus*	R,M,T	Copper chloride or sulfate	30	7 days	Chronic value (growth)	44	-	Hughes et al. 1989

Appendix C2. Other Data on Effects of Copper on Saltwater Organisms

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Sheepshead minnow (<24 hr), *Cyprinodon variegatus*	R,M,T	Copper chloride or sulfate	30	7 days	Chronic value (growth and survival)	177	-	Hughes et al. 1989
Sheepshead minnow (<24 hr), *Cyprinodon variegatus*	R,M,T	Copper chloride or sulfate	30	7 days	Chronic value (growth and survival)	177	-	Hughes et al. 1989
Sheepshead minnow (<24 hr), *Cyprinodon variegatus*	R,M,T	Copper chloride or sulfate	30	7 days	Chronic value (growth)	177	-	Hughes et al. 1989
Sheepshead minnow (24 hr), *Cyprinodon variegatus*	R,U	Copper sulfate	32	7 days	LC50	471.5	-	Morrison et al. 1989
Sheepshead minnow (24 hr), *Cyprinodon variegatus*	R,U	Copper sulfate	32	7 days	IC50 (growth)	351.6	-	Morrison et al. 1989
Sheepshead minnow (24 hr), *Cyprinodon variegatus*	R,M,T	Copper nitrate	34-35	96 hr	LC50	>220	-	Hutchinson et al. 1994
Mummichog, *Fundulus heteroclitus*	R,U	Copper chloride	20	21 days	Histopathology (lesions)	<500	-	Gardner and LaRoche 1973
Mummichog, *Fundulus heteroclitus*	S,M,T	Copper chloride	-	96 hr	Enzyme inhibition	600	-	Jackim 1973
Mummichog (<23 days), *Fundulus heteroclitus*	S,M,T	Copper sulfate	8-12	48 hr	LC50	19,000	-	Burton and Fisher 1990
Topsmelt (sperm), *Atherinops affinis*	S,M,T	Copper chloride	-	15 min	EC50 (fertilization)	109	-	Anderson et al. 1991
Topsmelt (embryo), *Atherinops affinis*	S,M,T	Copper chloride	33	12 days	EC50 (hatching)	146	-	Anderson et al. 1991
Topsmelt (<24 hr) *Atherinops affinis*	R,M,T	Copper chloride	-	7 days	LC50	365	-	McNulty et al. 1994
Topsmelt (9 day) *Atherinops affinis*	R,M,T	Copper chloride	-	7 days	LC50	134	-	McNulty et al. 1994
Topsmelt (9 day) *Atherinops affinis*	R,M,T	Copper chloride	34	7 days	LC50	162	-	Anderson et al. 1994
Topsmelt (9 day) *Atherinops affinis*	R,M,T	Copper chloride	34	7 days	LC50	274	-	Anderson et al. 1994
Topsmelt (9 day) *Atherinops affinis*	R,M,T	Copper chloride	34	7 days	LC50	169.1	-	Anderson et al. 1994
Topsmelt (9 day) *Atherinops affinis*	R,M,T	Copper chloride	22	7 days	LC50	55.7	-	Anderson et al. 1994
Topsmelt (9 day) *Atherinops affinis*	R,M,T	Copper chloride	22	7 days	LC50	58.4	-	Anderson et al. 1994
Topsmelt (9 day) *Atherinops affinis*	R,M,T	Copper chloride	10	7 days	LC50	5.66	-	Anderson et al. 1994
Topsmelt (9 day) *Atherinops affinis*	R,M,T	Copper chloride	17	7 days	LC50	<10	-	Anderson et al. 1994
Topsmelt (9 day) *Atherinops affinis*	R,M,T	Copper chloride	25	7 days	LC50	29.9	-	Anderson et al. 1994
Topsmelt (9 day) *Atherinops affinis*	R,M,T	Copper chloride	34	7 days	LC50	53.6	-	Anderson et al. 1994

Appendix C2. Other Data on Effects of Copper on Saltwater Organisms

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Inland silverside (7 day), *Menidia beryllina*	R,U	Copper sulfate	32	7 days	LC50	286.4	-	Morrison et al. 1989
Inland silverside (7 day), *Menidia beryllina*	R,U	Copper sulfate	32	7 days	IC50 (growth)	483.5	-	Morrison et al. 1989
Atlantic silverside, *Menidia menidia*	-	-	-	96 hr	Histopathological lesions	<500	-	Gardner and LaRoche 1973
Yellowtail snapper (embryo), *Ocyurus chrysurus*	S,U	Copper sulfate	36	24 hr	EC50 (viable hatch)	>250	-	Rumbold and Snedaker 1997
Sheepshead porgy (28-30 cm), *Archosargus probatocephalus*	S,U	Copper chloride	30-32	72 hr	hyperactivity	100	-	Steele 1985
Sheepshead porgy (28-30 cm), *Archosargus probatocephalus*	S,U	Copper chloride	30-32	72 hr	7-day latent hypoactivity	100	-	Steele 1985
Sheepshead porgy (28-30 cm), *Archosargus probatocephalus*	S,U	Copper chloride	30-32	72 hr	43% mortality after 3 weeks	200	-	Steele 1985
Pinfish, *Lagodon rhomboides*	S,U	-	-	14 days	LC50	150	-	Engel et al. 1976
Spotted seatrout (embryo), *Cynoscion nebuloosus*	S,U	Copper sulfate	35.9	48 hr	EC50 (normal development)	118.6	-	Rumbold and Snedaker 1997
Spot, *Leiostomus xanthurus*	S,U	-	-	14 days	LC50	160	-	Engel et al. 1976
Atlantic croaker, *Micropogonias undulatus*	S,U	-	-	14 days	LC50	210	-	Engel et al. 1976
Winter flounder, *Pseudopleuronectes americanus*	F,M,T	Copper sulfate	-	14 days	Histopathological lesions	180	-	Baker 1969
Striped bass (16 days), Morone saxatilis	R, M		1.5	-	LC50	24		Wright 1988

a S = static; R = renewal; F = flow-through; M = measured; U = unmeasured; T = total metal concentration measured; D = dissolved metal concentration; I = ionic

b Results are expressed as copper, not as the chemical

c Dissolved copper; No other measurement reported

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

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

Molecular Weights	Atomic Weights
$NaHCO_3$ = 84.03	Na = 22.98
$CaSO_4.2H_2O$ = 172.12	Ca = 40.08
$MgSO_4$= 120.37	Mg = 24.31
KCl = 74.55	K = 39.10
SO_4 = 96.06	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 $CaSO_4.2H_2O$/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 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 D-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	---	---	---	---

State	POC	DOC	Streams Est. TOC	Est. DOC:TOC	POC	DOC	Lakes 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 D-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 D-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	Cl
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

Appendix D-5. Results of the Sample Analysis of New and Clinch Rivers and Sinking Creek, VA.

Samples were analyzed August and September 2000, under WA 1-20. Water was collected for analysis by Dr. Don Cherry, Virginia Polytechnic Institute and State University, Blacksburg, VA. Units are mg/L, except pH, which are standard units.

Sampling Point: New River

General Chemistry		*Metals*	
Parameter	**Value**	**Parameter**	**Value**
NO_3	0.7	**Ca**	15
Cl	6.1	**Mg**	0.6
Sulfate	9.8	**K**	2
Sulfide	0.05	**Na**	6.6
Alkalinity	52		
pH	8		
DOC	2		
TOC	2.25		

Sampling Point: Clinch River

General Chemistry		*Metals*	
Parameter	**Value**	**Parameter**	**Value**
NO_3	1	**Ca**	42
Cl	9.2	**Mg**	11
Sulfate	19	**K**	2.4
Alkalinity	150	**Na**	12
Hardness	150		
pH	8.3		
DOC	2.3		

Sampling Point: Sinking Creek

General Chemistry		*Metals*	
Parameter	**Value**	**Parameter**	**Value**
NO_3	0.6	**Ca**	33
Cl	2.6	**Mg**	1.1
Sulfate	5	**K**	6.7
Sulfide	0.05	**Na**	1.7
Alkalinity	130		
pH	8.1		
DOC	1.05		
TOC	1.3		

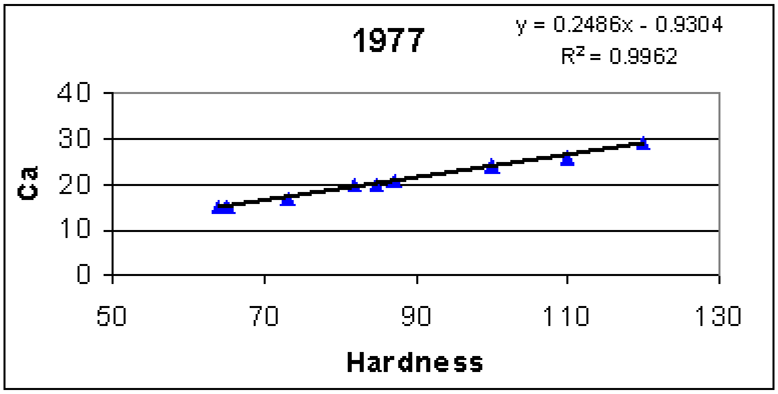
Appendix D-6. Water Composition of St. Louis River, MN, from USGS NASQAN and Select Relationships to Water Hardness

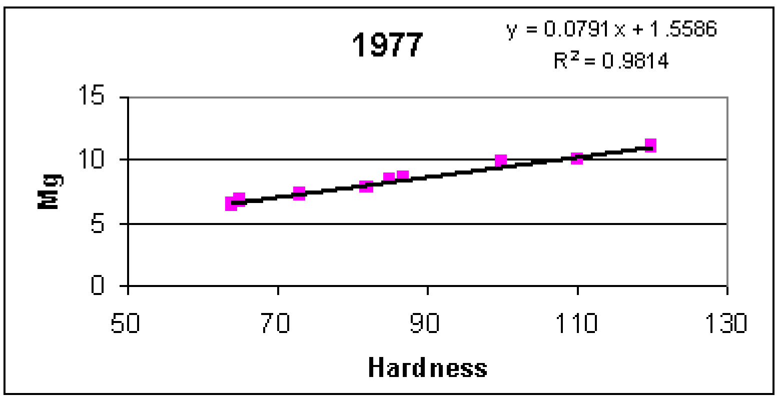
Date	pH	Hardness	Alkalinity	Ca	Mg	Na	K	Cl	SO_4	NO_3	DOC
19730222	6.8	68	53	17	6.3	11	1.6	14	14	0.19	
19730503	7.1	58	46	14	5.5	6.6	1.1	9.5	13	0.17	
19730816	6.9	70	51	17	6.6	7.6	1.2	9	20	0.01	
19731128	7	65	48	16	6.1	7.5	1.3	8.8	14		
19740221	7	64	48	16	5.8	8.9	1.3	12	14		
19740516	6.9	45	32	11	4.3	3.5	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	3.4	1	3.1	8		12

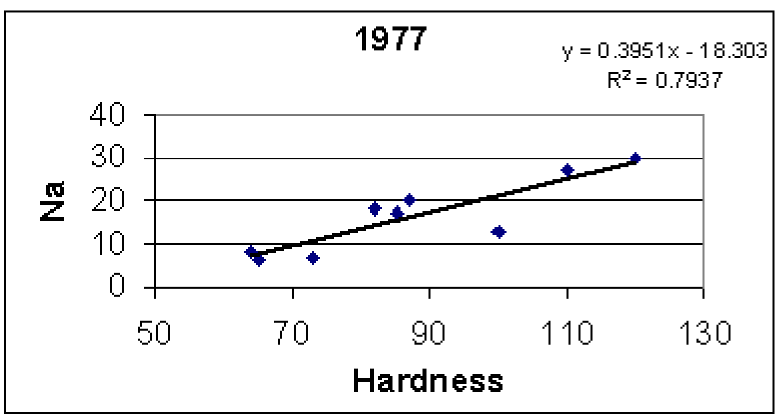
Date	pH	Hardness	Alkalinity	Ca	Mg	Na	K	Cl	SO_4	NO_3	DOC
19790329	7.6	80	63	19	8	8.4	2.3	7.8	13		
19790430	7.6	37	29	8.7	3.7	2.2	1.3	2.8	8.9		20
19790611	7.2	47	34	11	4.8	3.1	0.8	2.8	9.4		
19790723	7.6	73	55	17	7.3	3.9	0.9	3.7	8.9		30
19790827	7.2										
19791015	8.1	74	54	16	8.2	5	1.1	3.9	13	0.01	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	

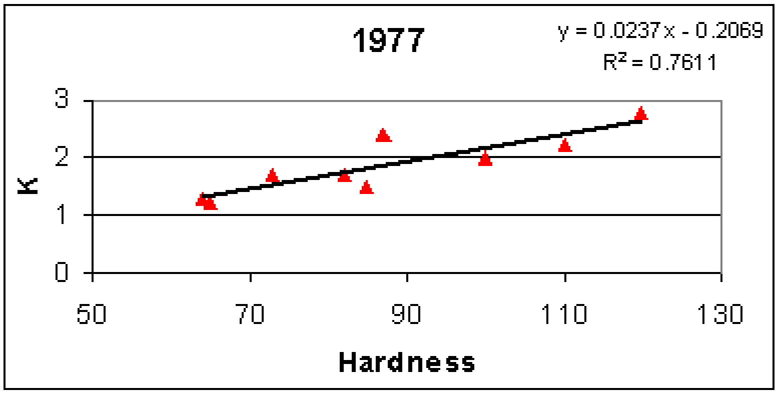
Date	pH	Hardness	Alkalinity	Ca	Mg	Na	K	Cl	SO_4	NO_3	DOC
19851203	7.4	73		16	8	4	1	4.2	18	0.16	
19860303	7.4	66		15	7	4	1	3.4	10	0.24	
19860407	7.3									0.19	
19860602	7.5	58		13	6.3	3.5	1	2.8	15	0.1	
19860818	7.9	74		15	8.9	4.6	1.2	3.7	24	0.1	
19861112	7.5	55		12	6	3.4	1.4	3.8	19	0.27	
19861210	7.3	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	

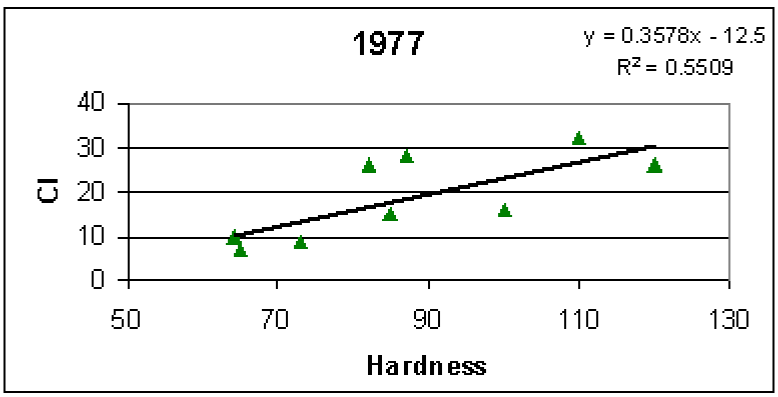
Date	pH	Hardness	Alkalinity	Ca	Mg	Na	K	Cl	SO_4	NO_3	DOC
19940216	7.3										
19940511	7.7	51		11	5.6	3.7	1.1	3.4	9.4	0.076	
MIN	6.4	30	25	7.5	2.5	2.1	0.2	0.2	3.8	0.01	10
MAX	9.5	130	110	29	15	30	8.5	32	36	0.37	37
MEAN	7.52	71.11	56.94	16.16	7.46	7.09	1.37	7.39	15.04	0.17	22.19

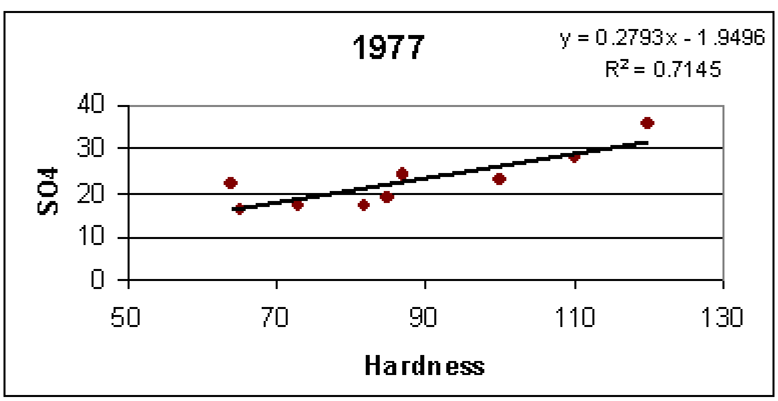

1977
y = 0.2486x - 0.9304
R² = 0.9962
40
30
20
10
0
Ca
50
70
90
110
130
Hardness


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
3
2
1
0
50
70
90
110
130
Hardness


1977
y = 0.3578x - 12.5
R² = 0.5509
Cl
40
30
20
10
0
50
70
90
110
130
Hardness


1977
y = 0.2793x - 1.9496
R² = 0.7145
SO4
40
30
20
10
0
50
70
90
110
130
Hardness

Appendix D-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)
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)
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 D-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 D-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 D-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 E. Saltwater Conversion Factors for Dissolved Values

Appendix E
Saltwater Conversion Factors for Dissolved Values

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U.S. Environmental Protection Agency
Office of Water
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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 E-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	

References

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Appendix F. BLM Input Data and Notes

Appendix F. 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)	
LUVA01S	1.7158	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	3.0893	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	2.9895	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	28.0060	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	27.1187	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	0.1732	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	0.0642	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	0.5126	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	0.3980	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	0.1634	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	0.2150	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	10.0781	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	10.2894	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	1.5125	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	1.6461	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	0.5932	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	1.8845	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	1.4506	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	1.0813	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	0.1332	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	0.1109	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	0.0909	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	0.0484	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	0.1266	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	0.0847	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	0.1114	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	0.1433	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	0.0788	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	0.0625	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	0.0576	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	0.0262	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	0.0194	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	0.0277	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 F. 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	0.0454	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	0.0395	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	0.0551	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	0.0211	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	0.0745	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	0.0806	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	0.0382	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	0.1566	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	0.0702	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	0.0535	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	0.0256	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	0.0364	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	0.0170	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	0.0293	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	0.2076	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	0.0911	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	0.0355	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	0.0140	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	0.6284	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	0.0656	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	0.1963	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	0.1457	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	1.4067	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	0.3981	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	0.0166	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	0.0308	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	0.0407	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	0.0228	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	0.0115	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	0.0196	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	0.0932	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	0.1114	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	0.0475	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	0.0298	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 F. 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	0.1330	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	0.1078	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	0.1239	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	0.1807	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	0.0077	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	0.3257	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	0.0175	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	0.0101	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	0.0061	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	0.0051	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	0.0066	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	0.1033	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	0.0576	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	0.0334	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	0.0334	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	0.0230	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	0.0866	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	0.0569	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	0.0108	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	0.0187	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	0.0069	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	0.0148	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	0.0730	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	0.0822	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	0.0065	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	0.0130	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	0.0171	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	0.0175	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	0.0311	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	0.0376	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	0.0477	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	0.1224	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	0.1347	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	0.1035	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 F. 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
HYAZ01S	0.2206	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	0.1575	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	0.3502	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	0.0898	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	0.0868	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	0.2623	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	0.3754	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	29.6273	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	26.3192	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	4.2091	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	1.3372	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	1.4620	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	0.8147	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	4.0100	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	1.9796	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	0.4939	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	2.3421	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	6.7006	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	1.5177	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	0.3903	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	0.3737	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	0.1465	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	1.6934	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	0.4452	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	4.2106	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	5.5651	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	0.4559	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	1.0338	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	0.1889	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	0.2029	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	0.1710	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	0.5633	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	2.0313	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	0.8481	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 F. 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)	
ONMY03S	1.1217	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	0.1566	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	0.1284	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	0.0601	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	0.1587	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	0.2912	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	0.5590	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	0.4321	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	0.1791	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	0.1193	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	0.5189	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	0.6489	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	0.1457	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	0.1393	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	0.2120	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	1.9944	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	0.3390	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	1.2327	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	0.6126	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	0.9384	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	5.8066	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	1.5335	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	0.0656	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	0.4233	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	0.1243	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	1.3908	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	0.6969	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	0.3174	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	1.4750	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	0.7476	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	1.9559	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	5.7290	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	6.1696	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	2.7375	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 F. 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	2.4870	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	3.7268	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	4.2652	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	0.6317	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	0.8220	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	1.3021	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	1.9540	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	4.8185	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	2.7735	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	3.7268	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	6.3927	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	0.2311	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	0.1300	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	0.8021	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	0.4226	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	0.4110	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	1.1139	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	1.3545	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	0.5851	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	1.4835	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	0.9872	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	1.1667	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	2.1157	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	4.4046	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	3.9765	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	4.5865	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	3.7394	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	4.3216	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	10.8390	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	3.7022	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	29.9833	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	12.7822	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	5.7854	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	11.1072	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 F. 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
PIPR04S	1.4088	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	3.5374	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	0.1923	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	0.4486	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	0.7848	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	0.1007	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	0.2995	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	0.6353	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	0.3291	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	0.4571	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	0.2945	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	0.0536	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	0.1957	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	0.0858	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	0.2054	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	4.5177	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	9.8196	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	6.6067	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	10.0006	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	9.6130	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	4.8327	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	4.0277	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	4.6547	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	0.6934	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	4.2004	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	0.8415	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	4.3543	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	2.0950	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	5.5515	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	4.5180	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	6.1264	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	7.0053	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	11.0638	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	7.3217	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 F. 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
PIPR38S	9.6045	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	5.5658	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	3.7432	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	6.6608	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	8.1233	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	8.3422	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	7.7119	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	8.9807	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	9.6110	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	6.7076	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	7.8946	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	5.8380	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	6.5811	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	6.4808	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	5.1408	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	6.3992	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	7.3246	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	6.0630	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	4.6526	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	4.1939	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	4.5177	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	6.3135	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	5.5732	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	7.3483	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	7.7886	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	9.0948	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	6.3665	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	6.6569	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	5.6622	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	6.4605	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	5.6753	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	4.2260	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	7.4910	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	5.3514	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 F. 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
PIPR72S	2.7296	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	1.3695	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	9.3865	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	12.6630	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	9.2347	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	7.9134	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	6.6518	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	10.0742	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	0.8019	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	8.4407	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	5.9596	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	6.1026	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	6.4883	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	7.7626	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	6.5085	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	6.4970	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	6.9041	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	8.2686	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	10.1330	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	10.6409	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	10.2715	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	7.7492	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	10.0406	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	9.6108	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	10.2877	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	2.6441	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	3.1176	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	5.3898	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	4.0158	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	3.6791	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	2.1414	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	3.2004	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	8.2240	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	5.1099	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 F. 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)	
PIPR106S	7.4717	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	6.7299	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	5.7199	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	7.0631	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	7.5267	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	7.5035	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	6.0200	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	7.4768	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	6.9113	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	6.6201	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	7.1813	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	7.8480	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	6.8379	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	9.6212	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	0.3530	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	0.4196	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	0.2051	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	4.0014	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	2.2409	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	3.3697	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	3.8346	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	1.8591	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	1.2189	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	1.4826	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	0.1002	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	1.2371	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	0.4681	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	0.4918	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	0.4459	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	0.3741	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	0.2142	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	0.1471	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	0.3435	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	3.2588	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 F. 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	0.0430	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	1.5807	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	0.0359	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	0.1178	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	0.1195	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	2.1998	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	0.5690	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	1.4682	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	1.8114	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	2.7182	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	2.6477	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	5.5908	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	11.6814	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	0.3130	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	0.1873	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	3.7420	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	6.1809	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	3.1551	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	26.4894	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	26.3896	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	27.9229	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	23.8414	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	7.5590	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	7.7563	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	7.8675	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	8.6770	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	5.1937	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	10.2981	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	10.1579	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	11.8023	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	11.0865	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	0.6913	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	2.4569	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

Notes:

Unless otherwise noted, a value of 10% humic acid and a value of 0.0003 mg/L sulfide were assumed for all tests (HydroQual 2001).

1. Temperature value used here is either the mean or the midpoint of the range measured for this specific test or for a group of tests reported in this study.
2. pH value used here is either the mean or the midpoint of the range measured for this specific test or for a group of tests reported in this study.
3. The dissolved copper LC50/EC50 used here was calculated as 96% of the reported total LC50/EC50 value (based on Stephan 1995).
4. A default reconstituted water DOC value of 0.5 mg/L was used for this test (see U.S. EPA 2003).
5. Alkalinity and hardness values used are midpoints of nominal range for very hard reconstituted water (U.S. EPA 1993; ASTM 2000). Cations and anions were calculated stoichiometrically according to nominal concentrations of salts added (ASTM 2000; U.S. EPA 1993), and adjusted according to the expected hardness (see U.S. EPA 2003).
6. Hardness value used here is either the mean or the midpoint of the range measured for this specific test or for a group of tests reported in this study.
7. Alkalinity value used here is either the mean or the midpoint of the range measured for this specific test or for a group of tests reported in this study.
8. Concentration of K is mean of values reported for Lake Superior water in Biesinger and Christensen (1972) and Erickson et al. (1996 a, b). Ca, Mg, Na, Cl, and SO_4 were derived in the same way, but were adjusted according to the measured hardness of the test water. DOC value is a mean of Lake Superior measurements taken by Greg Lien at U.S. EPA Duluth. See U.S. EPA 2003 for details.
9. DOC value is measured TOC of the same well water reported by McCrady and Chapman (1979).
10. Using available data for the Western Fish Toxicology Station (G. Chapman unpublished data, Samuelson 1976), regression analyses were conducted to quantify relationships between hardness and various ions (see U.S. EPA 2003). The resulting regression equations were used to estimate concentrations of Ca, Mg, Na, Cl, and S04. The mean K value was used because the relationship between K and hardness was non-significant.
11. Alkalinity and pH values used are midpoints of nominal range for soft reconstituted water (ASTM 2000; U.S. EPA 1993). Cations and anions were calculated stoichiometrically according to nominal concentrations of salts added (ASTM 2000; U.S. EPA 1993), and adjusted according to the measured hardness (see U.S. EPA 2003 for details.) Hardness, alkalinity, and pH values used are midpoints of nominal range for moderately hard reconstituted water (ASTM 2000; U.S. EPA 1993). Cations and anions were calculated stoichiometrically according to nominal concentrations of salts added (see U.S. EPA 2003 for details.) Although test organisms were fed during this test, test results were used because *Hyalella azteca* are cannibalistic and only a small amount of food (500 ul) was added to the test chambers (300 mls) such that the percentage addition is not so great as to significantly affect copper complexation.
12. The dissolved copper LC50 used here was calculated as 92% of the reported total LC50 value (based on percent dissolved reported by authors).
13. DOC value is based on measured TOC in the Lake Superior dilution water used and an estimate of the dissolved fraction (see U.S. EPA 2003).
14. Test was conducted in City of Blacksburg, VA tap water. Ionic concentrations and DOC were not measured. Ionic concentrations were estimated based on measurements made by the City of Blacksburg as well as USGS NASQAN data for the New River (see U.S. EPA 2003). These concentrations were adjusted according to the measured hardness of the test water. The DOC value used here was based on measurements of TOC made by the City of Blacksburg (see U.S. EPA 2003).
15. Ionic concentrations were estimated based on New River data included in the USGS NASQAN database, and were adjusted according to the measured hardness of the test water (see U.S. EPA 2003). The DOC value used here was based on a single measurement made on a New River water sample collected by Don Cherry in 2000.
16. Ionic concentrations were estimated based on measurements made on a single Clinch River water sample collected by Don Cherry in 2000, and were adjusted according to the measured hardness of the test water (see U.S. EPA 2003). The DOC value used here was based on a measurement made on the same water sample.
17. Alkalinity was estimated based on pH adjustment according to nomograph in Faust and Aly (1981) - see U.S. EPA 2003.
18. This test was conducted in a standard reconstituted water (ASTM 2000; U.S. EPA 1993). Ionic concentrations were calculated stoichiometrically according to nominal concentrations of salts added (ASTM 2000; U.S. EPA 1993), and adjusted according to the measured hardness of the test water (see U.S. EPA 2003 for details.)
19. DOC was measured in the dilution water, but was not detected (detection limit = 1 mg/L). DOC value used was 0.5 mg/L, which is one-half the detection limit and is consistent with the recommended default DOC value for reconstituted waters (see U.S. EPA 2003) pH was not reported; value used here is midpoint of nominal range for moderately hard reconstituted waters. The dissolved copper LC50 was calculated from the total copper LC50 using a 1.26 total to dissolved ratio reported by the author.
20. Hardness, alkalinity, and pH values used are midpoints of nominal range for hard reconstituted water (ASTM 2000; U.S. EPA 1993). Cations and anions were calculated stoichiometrically according to nominal concentrations of salts added (see U.S. EPA 2003 for details).
21. Test temperature was not reported; temperature used here is the temperature recommended by OECD (1981) because these methods were cited by the study's author.
22. Ionic composition calculated from Table 1 titled: Microcosm Medium (T82MV) and sediment composition, in ASTM (2000) publication E1366, vol. 11.05. T85MVK is recommended for culturing *Daphnia magna* and varies from T82MV by including 0.1 times the concentration of nitrate and phosphate.
23. TOC was measured in the dilution water, but was not detected (detection limit = 0.25 mg/L). DOC value used was 0.125 mg/L, which is one-half the TOC detection limit (see U.S. EPA 2003).
24. Ionic concentrations used here are those reported in the publication, which are estimated values based on known chemistry of well water and amounts of chemicals added.
25. Concentration of K is mean of values reported for Lake Superior water in Biesinger and Christensen (1972) and Erickson et al. (1996). Ca, Mg, Na, Cl, and SO_4 were derived in the same way, but were adjusted according to the measured hardness of the test water. See U.S. EPA 2003 for details.
26. Ionic concentrations were estimated based on measured values reported for the source water in STORET, and adjusted according to the measured hardness of the test water (see U.S. EPA 2003).
27. Using available data for the St. Louis River from the USGS NASQAN database, regression analyses were conducted to quantify relationships between hardness and various ions (see U.S. EPA 2003). The resulting regression equations were used to estimate ionic concentrations of Ca, Mg, Na, Cl, and S04.

28. Concentrations of Na, K, Cl, and S04 are means of values reported for Lake Superior water in Biesinger and Christensen (1972) and Erickson et al. (1996) (see U.S. EPA 2003). Ca, Mg, and SO_4 were derived in the same way, but were adjusted according to the amounts of $CaSO_4$ or $MgSO_4$ added to the test water.
29. Concentrations of Na, K, Cl, and S04 are means of values reported for Lake Superior water in Erickson et al. (1996). Ca and Mg values were derived in the same way, but were adjusted according to the measured hardness of the test water. DOC value is a mean of Lake Superior measurements taken by Greg Lien at U.S. EPA Duluth. See U.S. EPA 2003 for details.
30. With the exception of sulfide and dissolved copper, all parameters listed here were measured either in the exposure chamber water (pH, temperature, total copper) or in the dilution water prior to testing (ions, alkalinity, DOC) and were reported by Welsh (1996).
31. Dilution water was not a standard reconstituted water mix; concentrations of salts added were reported in this study. Measurements of hardness and alkalinity were not reported in this study; values used here were estimated based on nominal concentrations of salts added. DOC value used here is based on subsequent DOC measurement made on the same laboratory's dilution water (data provided by Uwe Borgmann).
32. Sufficient Cerophyl was added for *C. tentans* to construct burrows during the exposure. The authors reported that the cerophyl was required as substrate and food by the test animals for growth and survival.
33. A default DOC value of 1.6 mg/L, applicable to tap and well waters, was used for this test (see U.S. EPA 2003).
34. Ionic concentrations for this water (Green-Duwamish River) were estimated based on measured values reported in Santos and Stoner (1973), and adjusted according to the measured hardness of the test water (see U.S. EPA 2003).
35. With the exception of sulfide and dissolved copper, all parameters listed here were measured either in the exposure chamber water (pH, hardness, alkalinity, temperature, total copper) or in the dilution water prior to testing (ions, alkalinity, TOC) and were reported by Chapman (1975 and/or 1978). TOC was assumed to be 100% dissolved.
36. DOC value is a measure of TOC in the Western Fish Toxicology Station well water, as reported in Chapman 1978.
37. Dilution water used in this test was taken from the Chehalis River. DOC was estimated based on data supplied by the USGS NASQAN database. Ionic concentrations were provided by the author (see U.S. EPA 2003).
38. With the exception of sulfide and total copper LC50s, all parameters listed here were measured either in the exposure chamber water or in the dilution water and were reported by Hagler Bailly (1996). Total copper was measured, but LC50s were not reported. We estimated total copper LC50s based on reported dissolved LC50s and percentages of total copper in dissolved form.
39. Tests reported by Fogels and Sprague (1977) and Howarth and Sprague (1978) were conducted in very hard well water or a mix of this well water and de-ionized water. Measurements of organic carbon, most ionic concentrations, and occasionally alkalinity were not made or not reported. Methods used for estimating these parameters are described in U.S. EPA 2003. The authors reported LC50s as dissolved copper concentrations, and no attempt was made here to estimate total copper LC50s.
40. Tests were conducted in dechlorinated City of Montreal tap water. Ionic concentrations given here are based on those reported for the dilution water (Anderson and Spear 1980 a, b) and adjusted slightly based on measured test water hardness.
41. Tests were conducted in water collected from Pinto Creek, Arizona. Author reported concentrations of Ca, Mg, Na, and SO_4. Default values were used for K, Cl, and DOC (Cl default was scaled according to measured hardness). LC50s were reported as dissolved copper; we have not attempted to estimate total copper values.
42. This test was conducted in dechlorinated tap water at the Chesapeake Biological Laboratory in Solomons, MD. Measurements of ions, alkalinity, and DOC were not reported, so default values were used here. Default values for alkalinity and ions are from HydroQual 2001, and all except alkalinity and K were adjusted according to the measured hardness of the test water.
43. This test was conducted in a mix of Lake Superior water and laboratory reconstituted water. DOC value given here is an estimate based on the percent dilution of Lake Superior water and DOC measurements made on Lake Superior water by Greg Lien at U.S. EPA Duluth (see U.S. EPA 2003).
44. This test was conducted in a laboratory reconstituted water. DOC value is based on measurements taken by Greg Lien on reconstituted water used at U.S. EPA Duluth (see U.S. EPA 2003).
45. This test was conducted in Lake Superior water with added humic acid (additional salts may have been added). DOC value here is estimated based on Lake Superior DOC (see note 60) and nominal additions of humic acid. The percent humic acid was also adjusted accordingly.
46. Measurements of alkalinity and ions were not reported for this test; alkalinity for similar test water reported in Birge et al. 1981 was used here. Ions were estimated based on concentrations reported in Birge et al. 1981 and adjusted according to measured test hardness. One of the acute tests with fathead minnows from this study was excluded because the minnows, which were held for 10 days at 220 mg/L water hardness, were subsequently tested at a hardness 100 mg/L without acclimation.
47. With the exception of dissolved copper, sulfide, and hardness, all parameters listed here were measured either in the exposure chamber water (pH, temperature, total copper) or in the dilution water prior to testing (ions, alkalinity, DOC) (Welsh et al. 1993). Some of these data were not reported by Welsh et al. (1993), but were provided to EPA by the primary author. Hardness was calculated based on measured concentrations of Ca and Mg (see U.S. EPA 2003).
48. This test was conducted in dechlorinated City of Denton, TX tap water, and although not reported by Bennet et al. (1995), alkalinity, pH, and temperature were measured in the test chambers. Data were supplied to EPA by the authors (see U.S. EPA 2003); means of all daily measurements of test chambers were used here. Ionic concentrations were not available for this test; default values (HydroQual 2001) adjusted for measured test hardness were used.
49. This test was conducted in carbon filtered, millipore Ann Arbor tap water, and the DOC was assumed to be 0.5 mg/L (default for reconstituted waters). Concentrations of Ca and Mg were calculated based on reported total hardness and Ca hardness. Default values adjusted according to measured hardness were used for other ions (K was not adjusted; see U.S. EPA 2003).
50. This test was conducted in natural lake water (Lake Cultus, BC). The mean “soluble organic carbon” (DOC) value reported by the author for this lake was used here. Authors reported sulfate concentrations in the dilution water, but did not report any other anion or cation concentrations. These concentrations were estimated using default values from (HydroQual 2001), adjusting all except K according to the measured hardness of the test water.
51. A default DOC value of 0.3 mg/L for ultra-pure water was used for this test (see U.S. EPA 2003).
52. This test was conducted in tap water from an unspecified source. Authors did not report a DOC concentration for this water, but stated that it was “free from... organic matter.” On this basis, a

default value of 0.5 mg DOC/L was used. Ionic concentrations were estimated using default values from (HydroQual 2001), adjusting all except K according to the measured hardness of the test water.

53. Alkalinity value used is the midpoint of nominal range for soft reconstituted water (ASTM 2000; U.S. EPA 1993). Cations and anions were calculated stoichiometrically according to nominal concentrations of salts added (ASTM 2000; U.S. EPA 1993), and adjusted according to the measured hardness (see U.S. EPA 2003 for details.)
54. This test was conducted in a non-standard reconstituted water (Kristen Long's recipe). Ionic concentrations were calculated stoichiometrically according to nominal concentrations of salts added and adjusted according to the measured hardness.
55. With the exception of sulfide, all parameters listed were measured in the exposure chamber.
56. This test was conducted in a non-standard reconstituted water (Kristen Long's recipe). Ionic concentrations were calculated stoichiometrically according to nominal concentrations of salts added and adjusted according to the measured hardness.

Appendix G. Hardness Slopes

Appendix G. Hardness Slopes

As discussed in Section 5.1.1, EPA's earlier freshwater copper criteria recommendations were hardness-dependent values. Although characterized as "hardness-dependent," EPA recognized that these adjusted criteria not only reflected the influence of hardness on copper toxicity; hardness was also a surrogate for other covarying water quality parameters. In order to compare the new BLM-based criteria with updated hardness-dependent criteria an overall or "pooled slope" was needed to normalize the acute toxicity data to a standard hardness for calculating criteria. A pooled hardness slope was derived using all appropriate acute toxicity data, regardless of the quality rating assigned, according to the procedures in the 1985 Guidelines.

To account for the apparent relationship of copper acute toxicity to hardness, an analysis of covariance (Dixon and Brown 1979; Netter and Wasserman 1974) was performed using WINKS statistical software (WINKS ETC) to calculate the pooled slope for hardness using the natural logarithm of the acute value as the dependent variable, species as the treatment or grouping variable, and the natural logarithm of hardness as the covariate or independent variable. The pooled slope is a regression slope from a pooled data set, where every variable is adjusted relative to its mean. The species are adjusted separately, then pooled for a single conventional least squares regression analysis. The slope of the regression line is the best estimate of the all-species relationship between toxicity and hardness.

This analysis of covariance model was fit to the data contained in this appendix for the seven species for which definitive acute values are available over a range of hardness such that the highest hardness is at least three times the lowest, and the highest is also at least 100 mg/L higher than the lowest. Other species either did not meet these criteria, the organisms were fed, or as with *D. pulex, D. pulicaria* and *H. azteca* did not show any hardness-toxicity trend, possibly due to differences in exposure methods such as unusual chemical composition of the dilution water.

A list of the species, acute toxicity and hardness values, and the slopes used to estimate the pooled hardness slope are included in this appendix. The slopes for the seven species ranged from 0.4349 to 0.8963, and the pooled slope for these seven species was 0.9584. An F-test was used to test whether a model with separate species slopes for each species gives significantly better fit to the data than the model with parallel slopes. This test showed that the separate slopes model is not significantly better, and therefore the slopes are not significantly different than the overall pooled slope (P=0.39).

Results of Covariance Analysis of Freshwater Acute Toxicity Versus Hardness

Species	n	Slope	R2 Value	95% Confidence Limits		Degrees of Freedom
Ceriodaphnia dubia	27	0.8821	0.6063	0.5893	1.1749	25
Daphnia magna	46	0.7495	0.6174	0.5702	0.9288	44
Oncorhynchus clarki	11	0.6461	0.4184	0.0717	1.2204	9
Oncorhynchus mykiss	56	0.6245	0.6557	0.5010	0.7480	54
Oncorhynchus tshawytscha	12	0.8963	0.6064	0.3875	1.4051	10
Pimephales promelas	159	0.4349	0.4447	0.3583	0.5116	157
Lepomis macrochirus	6	0.7282	0.8499	0.3033	1.1531	4
All of the above	317	0.9584	0.5098	0.8542	1.0625	303

($p = 0.389$)

Appendix G. Hardness Slopes

Species	Lifestage	Method	Hardness (mg/L as CaCO3)	LC50 or EC50 Total (ug/L)	Reference
Ceriodaphnia dubia	<4 h	S,M,T	52	19.00	Carlson et al. 1986
Ceriodaphnia dubia	<4 h	S,M,T	52	17.00	Carlson et al. 1986
Ceriodaphnia dubia	<4 h	S,M,T	36	20.00	Carlson et al. 1986
Ceriodaphnia dubia	<4 h	S,M,T	36	18.00	Carlson et al. 1986
Ceriodaphnia dubia	<12 h	S,M,D	45	26.04	Belanger et al. 1989
Ceriodaphnia dubia	<12 h	S,M,D	45	17.71	Belanger et al. 1989
Ceriodaphnia dubia	<12 h	S,M,D	45	31.25	Belanger et al. 1989
Ceriodaphnia dubia	<12 h	S,M,D	45	25.00	Belanger et al. 1989
Ceriodaphnia dubia	<12 h	S,M,D	45	29.17	Belanger et al. 1989
Ceriodaphnia dubia	<12 h	S,M,D	45	33.33	Belanger et al. 1989
Ceriodaphnia dubia	<12 h	S,M,D	45	23.96	Belanger et al. 1989
Ceriodaphnia dubia	<12 h	S,M,D	45	20.83	Belanger et al. 1989
Ceriodaphnia dubia	<12 h	S,M,D	45	19.79	Belanger et al. 1989
Ceriodaphnia dubia	<12 h	S,M,D	94.1	27.08	Belanger et al. 1989
Ceriodaphnia dubia	<12 h	S,M,D	94.1	21.88	Belanger et al. 1989
Ceriodaphnia dubia	<12 h	S,M,D	94.1	28.13	Belanger et al. 1989
Ceriodaphnia dubia	<12 h	S,M,D	94.1	38.54	Belanger et al. 1989
Ceriodaphnia dubia	<12 h	S,M,D	94.1	35.42	Belanger et al. 1989
Ceriodaphnia dubia	<12 h	S,M,D	179	69.79	Belanger et al. 1989
Ceriodaphnia dubia	<12 h	S,M,D	179	39.58	Belanger et al. 1989
Ceriodaphnia dubia	<12 h	S,M,D	179	81.25	Belanger et al. 1989
Ceriodaphnia dubia	<12 h	S,M,D	179	84.38	Belanger et al. 1989
Ceriodaphnia dubia	<12 h	S,M,D	97.6	14.58	Belanger & Cherry 1990
Ceriodaphnia dubia	<12 h	S,M,D	97.6	29.17	Belanger & Cherry 1990
Ceriodaphnia dubia	<12 h	S,M,D	97.6	32.29	Belanger & Cherry 1990
Ceriodaphnia dubia	<12 h	S,M,D	182	58.33	Belanger & Cherry 1990
Ceriodaphnia dubia	<12 h	S,M,D	182	87.50	Belanger & Cherry 1990
Daphnia magna	<24 h	S,M,T,I	100	31.80	Borgmann & Ralph 1983
Daphnia magna	<24 h	S,M,I	100	35.60	Borgmann & Charlton 1984
Daphnia magna	1 d	S,M,T	39	9.10	Nebeker et al. 1986a
Daphnia magna	1 d	S,M,T	39	11.70	Nebeker et al. 1986a
Daphnia magna	<2 h	S,M,T	38	6.60	Nebeker et al. 1986a
Daphnia magna	<2 h	S,M,T	38	9.90	Nebeker et al. 1986a
Daphnia magna	1 d	S,M,T	39	11.70	Nebeker et al. 1986a
Daphnia magna	<4 h	S,M,T	39	6.70	Nebeker et al. 1986a
Daphnia magna	1 d	S,M,T	26	9.10	Nebeker et al. 1986a
Daphnia magna	<2 h	S,M,T	27	5.20	Nebeker et al. 1986a
Daphnia magna	<24 h	S,M,T	170	41.20	Baird et al. 1991
Daphnia magna	<24 h	S,M,T	170	10.50	Baird et al. 1991
Daphnia magna	<24 h	S,M,T	170	20.60	Baird et al. 1991
Daphnia magna	<24 h	S,M,T	170	17.30	Baird et al. 1991
Daphnia magna	<24 h	S,M,T	170	70.70	Baird et al. 1991
Daphnia magna	<24 h	S,M,T	170	31.30	Baird et al. 1991
Daphnia magna	<24 h	S,M,I	109.9	7.10	Meador 1991
Daphnia magna	<24 h	S,M,I	109.9	16.40	Meador 1991
Daphnia magna	<24 h	S,M,I	109.9	39.90	Meador 1991
Daphnia magna	<24 h	S,M,I	109.9	18.70	Meador 1991
Daphnia magna	<24 h	S,M,I	109.9	18.90	Meador 1991
Daphnia magna	<24 h	S,M,I	109.9	39.70	Meador 1991
Daphnia magna	<24 h	S,M,I	109.9	46.00	Meador 1991
Daphnia magna	<24 h	S,M,I	109.9	71.90	Meador 1991
Daphnia magna	<24 h	S,M,I	109.9	57.20	Meador 1991
Daphnia magna	<24 h	S,M,I	109.9	67.80	Meador 1991
Daphnia magna	<24 h	R,M,T	170	31.00	Lazorchak & Waller 1993
Daphnia magna	<24 h	R,M,T	170	38.00	Lazorchak & Waller 1993
Daphnia magna	<24 h	R,M,T	170	35.00	Lazorchak & Waller 1993
Daphnia magna	<24 h	R,M,T	170	58.00	Lazorchak & Waller 1993
Daphnia magna	<24 h	R,M,T	170	37.00	Lazorchak & Waller 1993
Daphnia magna	<24 h	R,M,T	170	51.00	Lazorchak & Waller 1993
Daphnia magna	<24 h	R,M,T	170	39.00	Lazorchak & Waller 1993
Daphnia magna	<24 h	R,M,T	170	50.00	Lazorchak & Waller 1993
Daphnia magna	<24 h	R,M,T	170	52.00	Lazorchak & Waller 1993
Daphnia magna	<24 h	R,M,T	170	31.00	Lazorchak & Waller 1993
Daphnia magna	<24 h	R,M,T	170	30.00	Lazorchak & Waller 1993
Daphnia magna	<24 h	R,M,T	170	46.00	Lazorchak & Waller 1993
Daphnia magna	<24 h	R,M,T	170	63.00	Lazorchak & Waller 1993
Daphnia magna	<24 h	S,M,T	52	26.00	Chapman et al. Manuscript
Daphnia magna	<24 h	S,M,T	105	30.00	Chapman et al. Manuscript

Appendix G. Hardness Slopes

Species	Lifestage	Method	Hardness (mg/L as CaCO3)	LC50 or EC50 Total (ug/L)	Reference
Daphnia magna	<24 h	S,M,T	106	38.00	Chapman et al. Manuscript
Daphnia magna	<24 h	S,M,T	207	69.00	Chapman et al. Manuscript
Daphnia magna	<24 h	S,M,T,D	7.1	4.80	Long's MS Thesis
Daphnia magna	<24 h	S,M,T,D	20.6	7.40	Long's MS Thesis
Daphnia magna	<24 h	S,M,T,D	23	6.50	Long's MS Thesis
Oncorhynchus clarki	larval, 0.34 g	S,M,T	169	80.00	Dwyer et al. 1995
Oncorhynchus clarki	larval, 0.57 g	S,M,T	169	60.00	Dwyer et al. 1995
Oncorhynchus clarki	7.4 cm, 4.2 g	F,M,T,D	205	398.91	Chakoumakos et al. 1979
Oncorhynchus clarki	6.9 cm, 3.2 g	F,M,T,D	69.9	197.87	Chakoumakos et al. 1979
Oncorhynchus clarki	8.8 cm, 9.7 g	F,M,T,D	18	41.35	Chakoumakos et al. 1979
Oncorhynchus clarki	8.1 cm, 4.4 g	F,M,T,D	204	282.93	Chakoumakos et al. 1979
Oncorhynchus clarki	6.8 cm, 2.7 g	F,M,T,D	83	186.21	Chakoumakos et al. 1979
Oncorhynchus clarki	7.0 cm, 3.2 g	F,M,T,D	31.4	85.58	Chakoumakos et al. 1979
Oncorhynchus clarki	8.5 cm, 5.2 g	F,M,T,D	160	116.67	Chakoumakos et al. 1979
Oncorhynchus clarki	7.7 cm, 4.4 g	F,M,T,D	74.3	56.20	Chakoumakos et al. 1979
Oncorhynchus clarki	8.9 cm, 5.7 g	F,M,T,D	26.4	21.22	Chakoumakos et al. 1979
Oncorhynchus mykiss	larval, 0.67 g	S,M,T	169	110.00	Dwyer et al. 1995
Oncorhynchus mykiss	larval, 0.48 g	S,M,T	169	50.00	Dwyer et al. 1995
Oncorhynchus mykiss	larval, 0.50 g	S,M,T	169	60.00	Dwyer et al. 1995
Oncorhynchus mykiss	swim-up, 0.25 g	R,M,T,D	44.1	46.70	Cacela et al. 1996
Oncorhynchus mykiss	swim-up, 0.25 g	R,M,T,D	44.6	24.20	Cacela et al. 1996
Oncorhynchus mykiss	swim-up, 0.20-0.24 g	R,M,T,D	38.7	3.54	Welsh et al. 2000
Oncorhynchus mykiss	swim-up, 0.20-0.24 g	R,M,T,D	39.3	8.44	Welsh et al. 2000
Oncorhynchus mykiss	swim-up, 0.20-0.24 g	R,M,T,D	89.5	17.92	Welsh et al. 2000
Oncorhynchus mykiss	swim-up, 0.20-0.24 g	R,M,T,D	89.67	33.33	Welsh et al. 2000
Oncorhynchus mykiss	12-16 cm	F,M	300	890.00	Calamari & Marchetti 1973
Oncorhynchus mykiss	alevin	F,M,T	23	28.00	Chapman 1975, 1978
Oncorhynchus mykiss	swim-up, 0.17 g	F,M,T	23	17.00	Chapman 1975, 1978
Oncorhynchus mykiss	parr, 8.6 cm, 6.96 g	F,M,T	23	18.00	Chapman 1975, 1978
Oncorhynchus mykiss	smolt, 18.8 cm, 68.19 g	F,M,T	23	29.00	Chapman 1975, 1978
Oncorhynchus mykiss	1.2-7.9 g	F,M,T,D	335	106.25	Fogels & Sprague 1977
Oncorhynchus mykiss	juvenile, 3.9 g	F,M,T	125	200.00	Spear 1977, Anderson & Spear 1980b
Oncorhynchus mykiss	juvenile, 29.1 g	F,M,T	125	190.00	Spear 1977, Anderson & Spear 1980b
Oncorhynchus mykiss	adult, 176 g	F,M,T	125	210.00	Spear 1977, Anderson & Spear 1980b
Oncorhynchus mykiss	1.1 g	F,M,T,D	32	23.33	Howarth & Sprague 1978
Oncorhynchus mykiss	2.2 g	F,M,T,D	31	30.10	Howarth & Sprague 1978
Oncorhynchus mykiss	1.4 g	F,M,T,D	31	31.25	Howarth & Sprague 1978
Oncorhynchus mykiss	2.7 g	F,M,T,D	30	31.25	Howarth & Sprague 1978
Oncorhynchus mykiss	3.2 g	F,M,T,D	101	41.67	Howarth & Sprague 1978
Oncorhynchus mykiss	0.71 g	F,M,T,D	99	34.48	Howarth & Sprague 1978
Oncorhynchus mykiss	0.80 g	F,M,T,D	102	31.98	Howarth & Sprague 1978
Oncorhynchus mykiss	1.5 g	F,M,T,D	101	48.23	Howarth & Sprague 1978
Oncorhynchus mykiss	1.6 g	F,M,T,D	99	49.90	Howarth & Sprague 1978
Oncorhynchus mykiss	1.5 g	F,M,T,D	100	50.10	Howarth & Sprague 1978
Oncorhynchus mykiss	10 g	F,M,T,D	100	84.48	Howarth & Sprague 1978
Oncorhynchus mykiss	1.0 g	F,M,T,D	98	89.48	Howarth & Sprague 1978
Oncorhynchus mykiss	1.0 g	F,M,T,D	366	72.92	Howarth & Sprague 1978
Oncorhynchus mykiss	1.7 g	F,M,T,D	371	85.63	Howarth & Sprague 1978
Oncorhynchus mykiss	6.6 g	F,M,T,D	361	310.42	Howarth & Sprague 1978
Oncorhynchus mykiss	1.8 g	F,M,T,D	371	537.50	Howarth & Sprague 1978
Oncorhynchus mykiss	0.90 g	F,M,T,D	360	321.88	Howarth & Sprague 1978
Oncorhynchus mykiss	3.1 g	F,M,T,D	364	115.63	Howarth & Sprague 1978
Oncorhynchus mykiss	1 g	F,M,T,D	194	176.04	Chakoumakos et al. 1979
Oncorhynchus mykiss	4.9 cm	F,M,T,D	194	88.85	Chakoumakos et al. 1979
Oncorhynchus mykiss	6.0 cm, 2.1 g	F,M,T,D	194	86.77	Chakoumakos et al. 1979
Oncorhynchus mykiss	6.1 cm, 2.5 g	F,M,T,D	194	107.29	Chakoumakos et al. 1979
Oncorhynchus mykiss	2.6 g	F,M,T,D	194	285.42	Chakoumakos et al. 1979
Oncorhynchus mykiss	4.3 g	F,M,T,D	194	133.33	Chakoumakos et al. 1979
Oncorhynchus mykiss	9.2 cm, 9.4 g	F,M,T,D	194	230.21	Chakoumakos et al. 1979
Oncorhynchus mykiss	9.9 cm, 11.5 g	F,M,T,D	194	171.88	Chakoumakos et al. 1979
Oncorhynchus mykiss	11.8 cm, 18.7 g	F,M,T,D	194	205.21	Chakoumakos et al. 1979
Oncorhynchus mykiss	13.5 cm, 24.9 g	F,M,T,D	194	535.42	Chakoumakos et al. 1979
Oncorhynchus mykiss	13.4 cm, 25.6 g	F,M,T,D	194	253.13	Chakoumakos et al. 1979
Oncorhynchus mykiss	6.7 cm, 2.65 g	F,M,T	9.2	2.80	Cusimano et al. 1986
Oncorhynchus mykiss	134 g	F,M,T	120	80.00	Seim et al. 1984
Oncorhynchus mykiss	parr	F,M,T,D,I	31	90.00	Mudge et al. 1993

Appendix G. Hardness Slopes

Species	Lifestage	Method	Hardness (mg/L as CaCO3)	LC50 or EC50 Total (ug/L)	Reference
Oncorhynchus mykiss	swim-up, 0.29 g	F,M,T,D	36.1	19.60	Cacela et al. 1996

Species	Lifestage	Method	Hardness (mg/L as CaCO3)	LC50 or EC50 Total (ug/L)	Reference
Oncorhynchus mykiss	swim-up, 0.25 g	F,M,T,D	36.2	12.90	Cacela et al. 1996
Oncorhynchus mykiss	swim-up, 0.23 g	F,M,T,D	20.4	5.90	Cacela et al. 1996
Oncorhynchus mykiss	swimup, 0.23 g	F,M,T,D	45.2	37.80	Cacela et al. 1996
Oncorhynchus mykiss	swim-up, 0.26 g	F,M,T,D	45.4	25.10	Cacela et al. 1996
Oncorhynchus mykiss	swim-up, 0.23 g	F,M,T,D	41.9	17.20	Cacela et al. 1996
Oncorhynchus tshawytscha	alevin, 0.05 g	F,M,T	23	26.00	Chapman 1975, 1978
Oncorhynchus tshawytscha	swim-up, 0.23 g	F,M,T	23	19.00	Chapman 1975, 1978
Oncorhynchus tshawytscha	parr, 9.6 cm, 11.58 g	F,M,T	23	38.00	Chapman 1975, 1978
Oncorhynchus tshawytscha	smolt, 14.4 cm, 32.46 g	F,M,T	23	26.00	Chapman 1975, 1978
Oncorhynchus tshawytscha	3 mo, 1.35 g	F,M,T,I	13	10.20	Chapman & McCrady 1977
Oncorhynchus tshawytscha	3 mo, 1.35 g	F,M,T,I	46	24.10	Chapman & McCrady 1977
Oncorhynchus tshawytscha	3 mo, 1.35 g	F,M,T,I	182	82.50	Chapman & McCrady 1977
Oncorhynchus tshawytscha	3 mo, 1.35 g	F,M,T,I	359	128.40	Chapman & McCrady 1977
Oncorhynchus tshawytscha	swim-up, 0.36-0.45 g	F,M,T,D	36.6	7.71	Welsh et al. 2000
Oncorhynchus tshawytscha	swim-up, 0.36-0.45 g	F,M,T,D	34.6	13.02	Welsh et al. 2000
Oncorhynchus tshawytscha	swim-up, 0.36-0.45 g	F,M,T,D	38.3	14.90	Welsh et al. 2000
Oncorhynchus tshawytscha	swim-up, 0.36-0.45 g	F,M,T,D	35.7	19.06	Welsh et al. 2000
Pimephales promelas	adult, 40 mm	S,M,T	103	310.00	Birge et al. 1983
Pimephales promelas	adult, 40 mm	S,M,T	103	120.00	Birge et al. 1983
Pimephales promelas	adult, 40 mm	S,M,T	262	390.00	Birge et al. 1983; Benson & Birge 1985
Pimephales promelas	---	S,M,T	52	55.00	Carlson et al. 1986
Pimephales promelas	---	S,M,T	52	85.00	Carlson et al. 1986
Pimephales promelas	---	S,M,T	36	180.00	Carlson et al. 1986
Pimephales promelas	---	S,M,T	36	95.00	Carlson et al. 1986
Pimephales promelas	<24 h	S,M,T	290	15.00	Schubauer-Berigan et al. 1993
Pimephales promelas	<24 h	S,M,T	290	44.00	Schubauer-Berigan et al. 1993
Pimephales promelas	<24 h	S,M,T	290	200.00	Schubauer-Berigan et al. 1993
Pimephales promelas	<24 h, 0.68 mg	S,M,T	19	4.82	Welsh et al. 1993
Pimephales promelas	<24 h, 0.68 mg	S,M,T	19.5	8.20	Welsh et al. 1993
Pimephales promelas	<24 h, 0.68 mg	S,M,T	16.5	31.57	Welsh et al. 1993
Pimephales promelas	<24 h, 0.68 mg	S,M,T	17	21.06	Welsh et al. 1993
Pimephales promelas	<24 h, 0.68 mg	S,M,T	19	35.97	Welsh et al. 1993
Pimephales promelas	<24 h, 0.68 mg	S,M,T	17	59.83	Welsh et al. 1993
Pimephales promelas	<24 h, 0.68 mg	S,M,T	17	4.83	Welsh et al. 1993
Pimephales promelas	<24 h, 0.68 mg	S,M,T	17.5	70.28	Welsh et al. 1993
Pimephales promelas	<24 h, 0.68 mg	S,M,T	18.5	83.59	Welsh et al. 1993
Pimephales promelas	<24 h, 0.68 mg	S,M,T	18.5	182.00	Welsh et al. 1993
Pimephales promelas	larval, 0.32 g	S,M,T	173	290.00	Dwyer et al. 1995
Pimephales promelas	larval, 0.56 g	S,M,T	173	630.00	Dwyer et al. 1995
Pimephales promelas	larval, 0.45 g	S,M,T	173	400.00	Dwyer et al. 1995
Pimephales promelas	larval, 0.39 g	S,M,T	173	390.00	Dwyer et al. 1995
Pimephales promelas	3.2-5.5 cm, 0.42-3.23 g	S,M,T	165	450.00	Richards & Beitinger 1995
Pimephales promelas	2.8-5.1 cm, 0.30-2.38 g	S,M,T	159	297.00	Richards & Beitinger 1995
Pimephales promelas	1.9-4.6 cm, 0.13-1.55 g	S,M,T	168	311.00	Richards & Beitinger 1995
Pimephales promelas	3.0-4.8 cm, 0.23-1.36 g	S,M,T	167	513.00	Richards & Beitinger 1995
Pimephales promelas	<24 h	S,M,T,D	45.540586	62.23	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	45.540586	190.50	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	44.539694	68.58	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	44.539694	168.91	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	44.539694	94.62	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	45.540586	143.51	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	45.04014	120.65	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	45.04014	196.85	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	138.123096	133.35	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	151.134692	184.15	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	138.123096	304.80	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	139.123988	292.10	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	47.041924	133.35	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	37.033004	92.71	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	60.05352	152.40	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	76.067792	177.80	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	103.091876	203.20	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	103.091876	190.50	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	107.095444	196.85	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	134.119528	234.95	Erickson et al. 1996a,b

Species	Lifestage	Method	Hardness (mg/L as CaCO3)	LC50 or EC50 Total (ug/L)	Reference
Pimephales promelas	<24 h	S,M,T,D	45.04014	146.05	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	46.041032	171.45	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	45.04014	152.40	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	45.04014	184.15	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	44.039248	203.20	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	45.04014	203.20	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	46.041032	203.20	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	189.168588	222.25	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	46.041032	146.05	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	75.0669	139.70	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	46.041032	139.70	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	74.066008	152.40	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	133.118636	203.20	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	76.067792	196.85	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	134.119528	266.70	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	52.046384	99.06	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	51.045492	111.13	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	50.0446	78.74	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	51.045492	92.71	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	51.045492	85.09	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	53.047276	123.19	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	53.047276	165.10	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	52.046384	190.50	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	47.041924	165.10	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	47.041924	127.00	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	47.041924	92.08	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	47.041924	66.68	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	140.12488	393.70	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	88.078496	317.50	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	59.052628	107.95	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	41.036572	67.95	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	27.024084	45.72	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	43.038356	177.80	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	25.0223	13.97	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	107.095444	304.80	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	87.077604	71.12	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	85.07582	83.82	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	88.078496	104.78	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	87.077604	139.70	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	87.077604	152.40	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	87.077604	260.35	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	87.077604	488.95	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	87.077604	203.20	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	251.223892	704.85	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	252.224784	952.50	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	252.224784	1244.60	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	251.223892	1485.90	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	200.1784	781.05	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	140.12488	476.25	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	90.08028	273.05	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	19.016948	22.23	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	34.030328	24.13	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	51.045492	36.83	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	29.025868	27.94	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	30.02676	26.67	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	27.024084	20.32	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	27.024084	26.67	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	90.08028	190.50	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	60.05352	109.86	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	120.10704	203.20	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	180.16056	209.55	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	91.081172	146.05	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	90.08028	165.10	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	93.082956	254.00	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	92.082064	311.15	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	91.081172	165.10	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	144.128448	920.75	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	292.260464	1073.15	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	440.39248	1003.30	Erickson et al. 1996a,b

Appendix G. Hardness Slopes

Species	Lifestage	Method	Hardness (mg/L as CaCO3)	LC50 or EC50 Total (ug/L)	Reference
Pimephales promelas	<24 h	S,M,T,D	217.193564	933.45	Erickson et al. 1996a,b

Appendix G. Hardness Slopes

Species	Lifestage	Method	Hardness (mg/L as CaCO3)	LC50 or EC50 Total (ug/L)	Reference
Pimephales promelas	<24 h	S,M,T,D	218.194456	742.95	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	212.189104	1879.60	Erickson et al. 1996a,b
Pimephales promelas	<24 h	S,M,T,D	92.082064	266.70	Erickson et al. 1996a,b
Pimephales promelas	adult	F,M,T	198	470.00	Mount 1968
Pimephales promelas	---	F,M,T	31	75.00	Mount & Stephan 1969
Pimephales promelas	5.6 cm, 1.6 g	F,M,T	200	440.00	Geckler et al. 1976
Pimephales promelas	4.7 cm	F,M,T	200	490.00	Geckler et al. 1976
Pimephales promelas	fry, 6 wk, 2.2 cm	F,M,T	202	490.00	Pickering et al. 1977
Pimephales promelas	subadult, 6 mo, 5.5 cm	F,M,T	202	460.00	Pickering et al. 1977
Pimephales promelas	---	F,M,T	48	114.00	Lind et al. Manuscript (1978)
Pimephales promelas	---	F,M,T	45	121.00	Lind et al. Manuscript (1978)
Pimephales promelas	---	F,M,T	46	88.50	Lind et al. Manuscript (1978)
Pimephales promelas	---	F,M,T	30	436.00	Lind et al. Manuscript (1978)
Pimephales promelas	---	F,M,T	37	516.00	Lind et al. Manuscript (1978)
Pimephales promelas	---	F,M,T	87	1586.00	Lind et al. Manuscript (1978)
Pimephales promelas	---	F,M,T	73	1129.00	Lind et al. Manuscript (1978)
Pimephales promelas	---	F,M,T	84	550.00	Lind et al. Manuscript (1978)
Pimephales promelas	---	F,M,T	66	1001.00	Lind et al. Manuscript (1978)
Pimephales promelas	30 d, 0.15 g	F,M,T,D	43.9	96.00	Spehar & Fiandt 1986
Pimephales promelas	60-90 d, 3.3 cm, 0.7 g	S,M,T	101	252.00	Bennett et al. 1995
Pimephales promelas	<24 h	F,M,T,D	47.041924	31.75	Erickson et al. 1996a,b
Pimephales promelas	<24 h	F,M,T,D	243.216756	117.48	Erickson et al. 1996a,b
Pimephales promelas	<24 h	F,M,T,D	255.727906	48.26	Erickson et al. 1996a,b
Pimephales promelas	<24 h	F,M,T,D	47.041924	73.03	Erickson et al. 1996a,b
Pimephales promelas	<24 h	F,M,T,D	45.04014	59.06	Erickson et al. 1996a,b
Pimephales promelas	<24 h	F,M,T,D	45.04014	78.74	Erickson et al. 1996a,b
Pimephales promelas	<24 h	F,M,T,D	45.540586	22.23	Erickson et al. 1996a,b
Pimephales promelas	<24 h	F,M,T,D	49.043708	6.99	Erickson et al. 1996a,b
Pimephales promelas	<24 h	F,M,T,D	45.04014	22.23	Erickson et al. 1996a,b
Pimephales promelas	<24 h	F,M,T,D	43.038356	107.32	Erickson et al. 1996a,b
Pimephales promelas	<24 h	F,M,T,D	45.540586	292.10	Erickson et al. 1996a,b
Pimephales promelas	<24 h	F,M,T,D	45.04014	81.28	Erickson et al. 1996a,b
Pimephales promelas	<24 h	F,M,T,D	45.04014	298.45	Erickson et al. 1996a,b
Pimephales promelas	<24 h	F,M,T,D	45.540586	241.30	Erickson et al. 1996a,b
Pimephales promelas	<24 h	F,M,T,D	45.04014	133.35	Erickson et al. 1996a,b
Pimephales promelas	<24 h	F,M,T,D	44.039248	93.98	Erickson et al. 1996a,b
Pimephales promelas	<24 h	F,M,T,D	44.039248	67.95	Erickson et al. 1996a,b
Pimephales promelas	<24 h	F,M,T,D	22.52007	4.76	Erickson et al. 1996a,b
Pimephales promelas	<24 h	F,M,T,D	24.021408	13.97	Erickson et al. 1996a,b
Pimephales promelas	<24 h	F,M,T,D	23.020516	29.85	Erickson et al. 1996a,b
Pimephales promelas	<24 h	F,M,T,D	21.519178	59.69	Erickson et al. 1996a,b
Lepomis macrochirus	3.58 cm, 0.63 g	R,M,D	85	2291.67	Blaylock et al. 1985
Lepomis macrochirus	12 cm, 35 g	F,M,T	45	1100.00	Benoit 1975
Lepomis macrochirus	10.3 cm, 18.6 g	F,M,T	200	8300.00	Geckler et al. 1976
Lepomis macrochirus	10.1 cm, 19.2 g	F,M,T	200	10000.00	Geckler et al. 1976
Lepomis macrochirus	2.8-6.8 cm	F,M,T	25.9	1000.00	Cairns et al. 1981
Lepomis macrochirus	3.58 cm, 0.63 g	F,M,D	85	1354.17	Blaylock et al. 1985

Appendix G. Hardness Slopes

SUMMARY OUTPUT

Overall Slope

Regression Statistics	
Multiple R	0.714033268
R Square	0.509843507
Adjusted R Square	0.508287455
St&ard Error	0.744214128
Observations	317

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	181.4715328	181.4715328	327.651897	1.05959E-50
Residual	315	174.4642206	0.553854669		
Total	316	355.9357534			

	Coefficients	*St&ard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-1.34057E-15	0.04179923	-3.20717E-14	1	-0.082240968	0.082240968
X Variable 1	0.958366107	0.052945018	18.10115734	1.05959E-50	0.854195537	1.062536676

Appendix H. Regression Plots

Appendix H. 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	Initial 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, *Ceriodaphnia dubia (Cinch River)*	Belanger et al. 1989	LC	Reproduction	16.60	33.6	1.15	19.36	14.03
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	Initial 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).

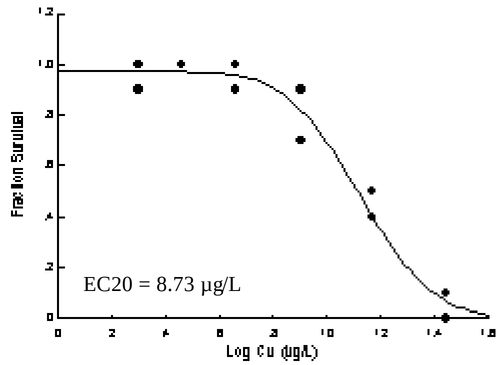
Pimephales notatus. An experimental design similar to that described by Mount and Stephan (1967) and Mount (1968) was used to examine the chronic effect of copper on the bluntnose minnow, *P. notatus* (Horning and Neiheisel 1979). Measured total copper concentrations were 4.3 (control), 18.0, 29.9, 44.1, 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.

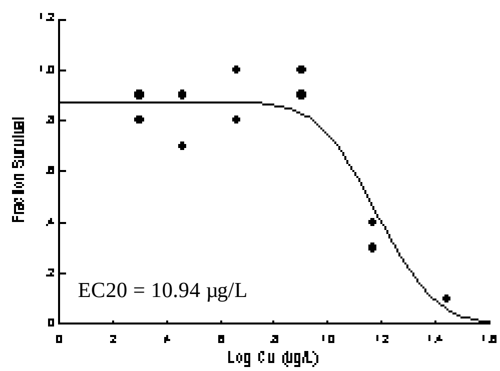
Catastomus commersoni. McKim et al. (1978) examined the survival and growth (expressed as standing crop) of embryo-larval and early juvenile white sucker exposed to copper. The embryo exposure was for 13 days, and the larval-early-juvenile exposure lasted 27 days. The NOAEC and LOAEC were 12.9 and 33.8 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.

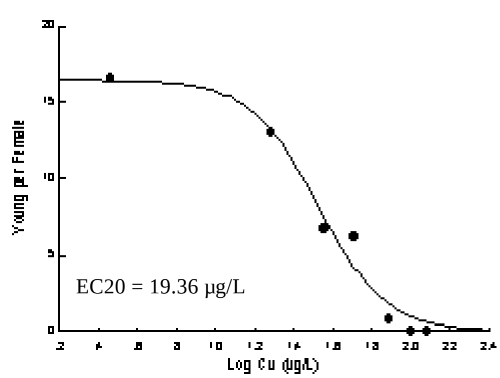
Campeloma decisum **(Test 1), Life-cycle, Arthur and Leonard 1970**



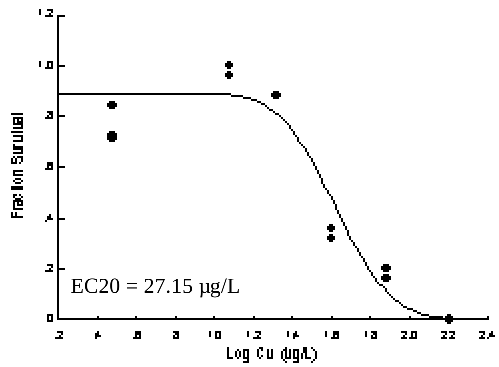
Campeloma decisum **(Test 2), Life-cycle, Arthur and Leonard 1970**



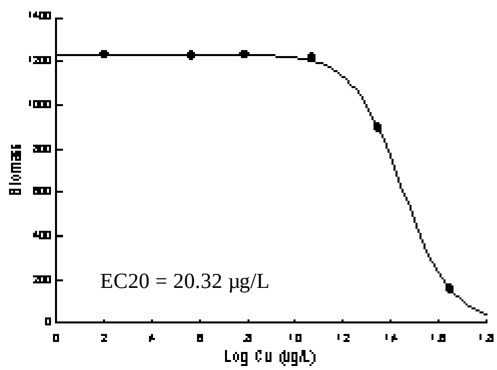
Ceriodaphnia dubia **(Clinch River), Life-cycle, Belanger et al. 1989**



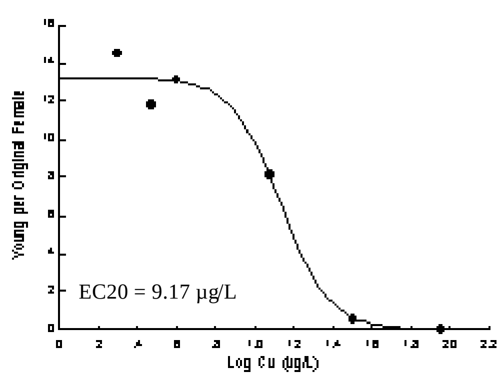
***Lepomis macrochirus*, Early Life-stage, Benoit 1975**



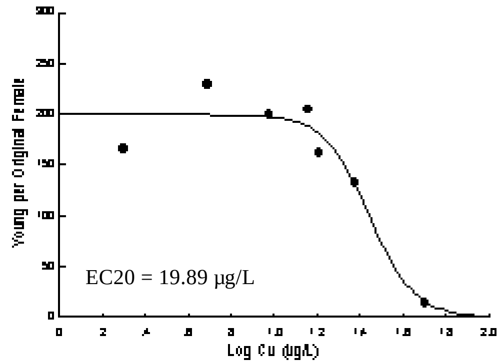
***Oncorhynchus mykiss*, Early Life-Stage, Besser et al. 2001**



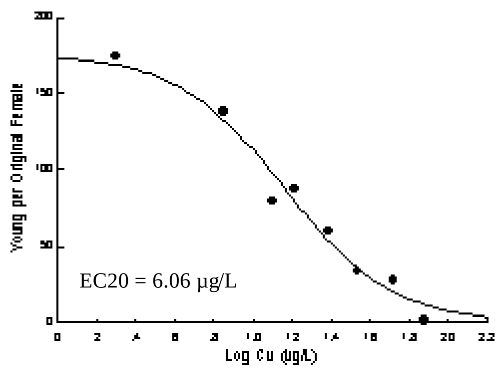
***Ceriodaphnia dubia*, Life-cycle, Carlson et al. 1986**



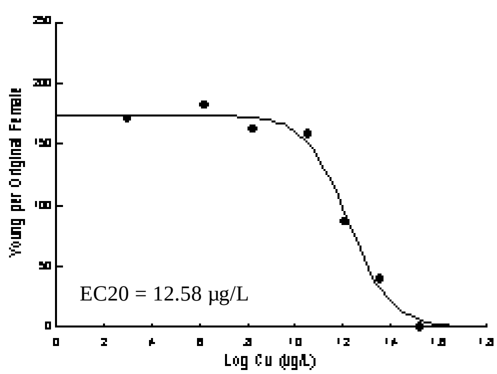
Daphnia magna **(Hardness 104), Life-cycle, Chapman et al. Manuscript**



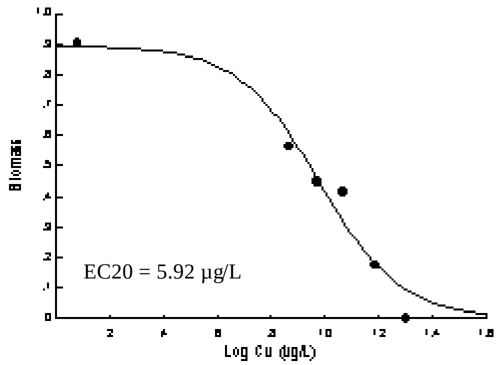
Daphnia magna **(Hardness 211), Life-cycle, Chapman et al. Manuscript**



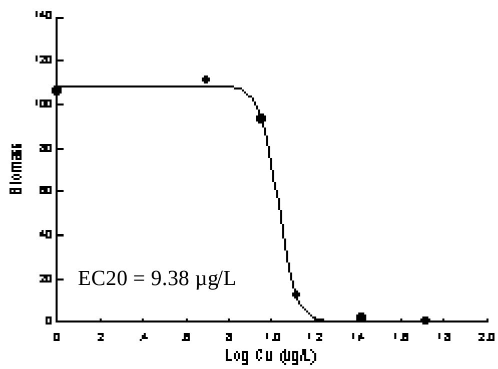
Daphnia magna **(Hardness 51), Life-cycle, Chapman et al. Manuscript**



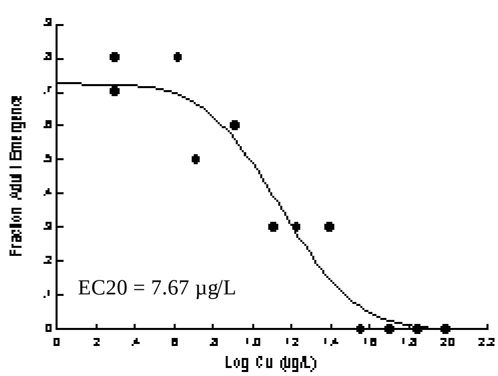
***Oncorhynchus tshawytscha*, Early Life-Stage, Chapman 1975 & 1982**



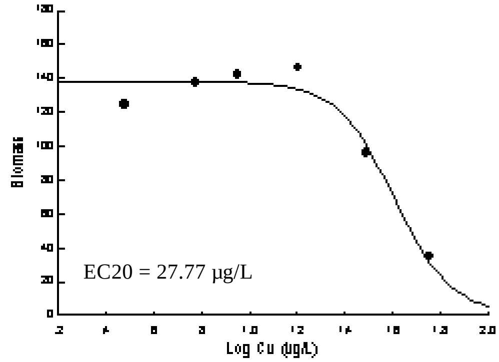
***Pimephales promelas*, Early Life-stage, Lind et al. 1978**



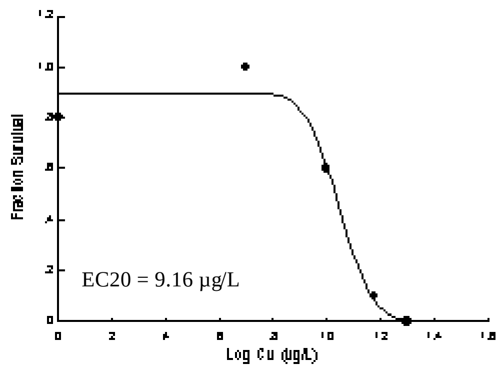
***Clistoronia magnifica*, Life-cycle, Nebeker et al. 1984a**



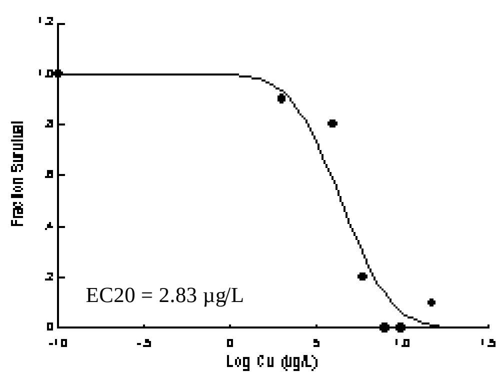
Oncorhynchus mykiss, Early Life-stage, Seim et al. 1984



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



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



Appendix I. Unused Data

APPENDIX I. 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).