# APPENDIX IX.8

# SITE-SPECIFIC WATER QUALITY BENCHMARKS AND MINE WATER DISCHARGE TOXICITY TESTING

## TABLE OF CONTENTS



## LIST OF TABLES

## TABLE OF CONTENTS (Continued)

## LIST OF TABLES (Continued)



## LIST OF FIGURES

# 1.0 DERIVATION OF SITE-SPECIFIC WATER QUALITY BENCHMARKS

## 1.1 Introduction

The Canadian Council of Ministers of the Environment (CCME) established Canadian Water Quality Guidelines (CWQG) that are nationally endorsed by the ten provinces, three territories, and the federal government. The CWQG are science-based goals for the quality of aquatic ecosystems, defined as numerical concentrations or narrative statements that should result in negligible risk to biota, their functions, or any interactions that are integral to sustaining ecosystem health.

The CWQG are generic recommendations based on the most current scientific information, but do not directly consider site-specific or management factors. Therefore, CWQG "should not be regarded as blanket values" (CCME 1999), and "science-based site-specific criteria, guidelines, objectives or standards may differ" from the CWQG (CCME 1999).

The CWQG for protection of aquatic life are not restricted to a particular species, but species-specific information is provided to allow water quality managers and other users to determine the appropriateness of the guideline. In cases where the guideline is not appropriate or unachievable, best scientific judgement may be used to modify derivation procedures and develop more meaningful benchmarks or objectives.

The CCME is currently in the process of developing a guidance manual for deriving site-specific numerical water quality objectives (MacDonald *et. al.* 2002). This draft document recognizes that the derivation of site-specific objectives requires extensive knowledge of the physical, chemical, and biological characteristics of the waterbody under consideration, as well as the social and economic characteristics of the local area.

The draft guidance manual (MacDonald *et al.* 2002) suggests some possible approaches and provides recommendations on rules for developing site-specific water quality objectives. Specifically, it states that preliminary water quality objectives may be recalculated using only toxicological information applicable to the site under investigation. However, it is recommended that specific rules should be adhered to when assessing the applicability of the data set to the site. These draft rules were considered in the development of site-specific water quality benchmarks developed for the Snap Lake Diamond Project.

While the CCME (1999) endorses a specific approach, it does not restrict water quality managers from deriving water quality objectives using other scientifically defensible approaches. For the purposes of the Snap Lake Diamond Project environmental

assessment (EA), species sensitivity distributions (SSD) were used to develop site-specific water quality benchmarks.

## 1.2 Species Sensitivity Distributions

Living organisms comprise a vast diversity of taxonomy, life history, physiology, morphology, behaviour, and geographic distributions. The biological differences mean that different species respond differently to a substance at a given concentration (*i.e.*, different species have different sensitivities). The variation amongst species sensitivities can be described by a statistical distribution function to yield SSD.

The basic assumption of the SSD concept is that the sensitivities of a set of species can be described by some distribution (*e.g.*, triangular, normal or logistic). Available toxicological data provide a sample of the distribution and are used to estimate the parameters of the SSD. The variance in sensitivity among test species and the mean can be used to develop an environmental quality criterion, which is a concentration expected to be safe to most species (Posthuma *et al.* 2001).

The use of SSDs to estimate the risk to the ecosystem have been formally accepted by the Water Environmental Research Foundation (WERF, Parkhurst *et al.* 1996), the Aquatic Risk Assessment and Mitigation Dialog Group (ARAMDG, Baker *et al.* 1994), and the ecological committee on FIFRA Risk Assessment Methods (ECOFRAM 1999). The first use of SSDs was in the derivation of Natural Ambient Water Quality Criteria (NAWQCs) by the United States Environmental Protection Agency (U.S. EPA) as early as 1978. The use of SSDs by the U.S. EPA led to the development of aquatic life criteria Tier 2 values (U.S. EPA 1995).

### 1.2.1 Methodology

The development of the SSDs requires three primary steps:

- selection of toxicity data;
- statistical analysis of toxicity data; and,
- interpretation of the output.

Within each step there are a number of decision rules that are followed to ensure that consistent data are used and that appropriate distributions are developed for each parameter assessed.

#### 1.2.1.1 Selection of Toxicity Data

The initial groundwork for the development of the toxicity database began with the inclusion of all primary acute and chronic toxicity data listed in the appropriate CCME water quality guidelines and U.S. EPA Ambient Water Quality Criteria documents. The toxicity database was expanded by querying the Aquatic Information Retrieval database on Toxicity (AQUIRE) and reviewing the scientific literature. The data set consists of data with consistent test endpoints such as mortality ($LC_{50}$) for acute toxicity tests and reduced survival, growth or reproduction for chronic studies. All chronic studies included in the toxicity database were completed as either early life-stage tests or life-cycle studies. Although the database does not include all available data, it consists of the primary data that meet both the requirements of the U.S. EPA and CCME guideline development protocol. The data set is considered to be statistically and ecologically representative of the community or set of species of interest.

The acute toxicity data was used in the species screening process because it represents the most abundant toxicity data available for most chemicals. The acute toxicity data were based on a $LC_{50}$ mortality endpoint or an $EC_{50}$ endpoint that is equivalent to mortality (*i.e.*, loss of mobility). However, the goal of this process was to develop site-specific water quality benchmarks that would provide protection to the majority of aquatic life as well as ecosystem function; therefore, chronic toxicity endpoints (*i.e.*, long-term survival, reproduction and growth) were used for the derivation of site-specific benchmarks.

Because of the limited toxicity data available on chronic endpoints, acute toxicity data with appropriate acute-chronic ratios (ACR) were used to predict chronic toxicity for some species. The use of ACR is a standard approach for estimating chronic toxicity from acute data (Stephan *et al.* 1985). An ACR is developed for some species by completing side-by-side acute and chronic toxicity tests. The resulting ratio between the acute and chronic endpoints can then be used to adjust other acute toxicity data to arrive at a predicted chronic toxicity value. While this method does not provide an exact measure of chronic toxicity it has proven to be accurate representation when no measured chronic toxicity information is available (Stephan *et al.* 1985).

Wherever measured chronic endpoints were available in the toxicity literature, these values took precedence over a predicted chronic value using an ACR. In these cases, the measured chronic value replaced any predicted chronic value for that species and was incorporated into the development of the SSDs.

Following the development of the toxicity database, test species were screened for inclusion or exclusion (*e.g.*, Table IX.8-1) based specifically on the relevance of the test species to a northern waterbody (*e.g.*, resident species screening). To complete this screening, the general rules for developing site-specific water quality objectives using a subset of toxicological data (MacDonald *et al.* 2002) was followed. The summarized rules applicable to this area are:

- toxicity data on species that are known to occur or may occur at the site can not be excluded;
- if a member of a family of freshwater fish may occur at the site, then toxicity data from any fish species within that family is maintained in the database; and,
- if a member of a class of freshwater invertebrates may occur at the site, then toxicity data from that invertebrate class is retained in the toxicity database.

Some of the general exclusion rules include:

- toxicity data on species that are known not to occur or are not likely to occur at the site can be excluded; and,
- acute toxicity data was excluded if measured chronic values were available for that species.

#### 1.2.1.2 Statistical Analysis of Toxicity Data

Following the screening of the toxicity database and selection of appropriate test species as valid representatives of the study area, statistical analysis of the data points was completed. The statistical analysis of the data consisted of three components:

- development of species mean values to summarize available data for a species;
- determination of the cumulative probability or percent of community affected; and,
- development of a statistical distribution to the available data set.

When the acute toxicity database includes more than one study and acute value for a given species, the geometric mean of the test results are used to represent the toxicity to the given species (Stephan *et al.* 1985). This process recognizes that there are potential differences in toxicity testing procedures and results and thus provides an accurate approximation of the acute toxicity concentration.

# Table IX.8-1
# Copper Toxicity Database

| Species | Common name | Hardness | LC50 | | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Reported | Adjusted to Hardness of 50 mg/L | | | | | | |
| Lumbriculus variegatus | worm | 30 | 150 | 242.7 | 242.7 | | | Included | A | Bailey & Liu 1980 |
| Limnodrilus hoffmeisteri | worm | 100 | 102 | 53.1 | 53.1 | | | Included | A | Wurtz & Bridges 1961 |
| Nais sp. | worm | 50 | 90 | 90.0 | 90.0 | | | Included | A | Rehwoldt *et al.* 1973 |
| Campeloma decisum | snail | 45 | 1700 | 1877.4 | 1877.4 | 11.9 | 156.2 | Included | A | Arthur & Leonard 1970 |
| Amnicola sp. (embryo) | snail | 50 | 9300 | 9300.0 | | | | Excluded | F | Rehwoldt *et al.* 1973 |
| Amnicola sp.(adult) | snail | 50 | 900 | 900.0 | 900.0 | | | Included | A | Rehwoldt *et al.* 1973 |
| Goniobasis livenscens | snail | 154 | 590 | 204.4 | | | | Included | A | Paulson *et al.* 1983 |
| Goniobasis livenscens | snail | 154 | 390 | 135.1 | 166.2 | | | Included | A | Paulson *et al.* 1983 |
| Gyraulus circumstriatus | snail | 100 | 108 | 56.2 | 56.2 | | | Included | A | Wurtz & Bridges 1961 |
| Physa heterostropha | snail | 100 | 69 | 35.9 | 35.9 | | | Included | A | Wurtz & Bridges 1961 |
| Physa integra | snail | 45 | 39 | 43.1 | 43.1 | 11.9 | 3.6 | Included | A | Arthur & Leonard 1970 |
| Corbicuta fluminea | asiatic clam | 64 | 40 | 31.7 | | | | Excluded | D | Rodgers *et al.* 1980 |
| Corbicuta fluminea | asiatic clam | 64 | 490 | 388.3 | 110.9 | | | Excluded | D | Rodgers *et al.* 1980 |
| Corbicula malinensis | asiatic clam | 50 | 7184.8 | 7184.8 | 7184.8 | | | Excluded | D | Harrison *et al.* 1984 |
| Anodonta imbecilis | mussel | 50 | 105.3 | 105.3 | 105.3 | | | Excluded | D | Keller and Zam 1991 |
| Corbiculina australis | orb-shell mussel | 50 | 5115.3 | 5115.3 | 5115.3 | | | Excluded | D | Harrison *et al.* 1984 |
| Alona Afinis | cladoceran | 50 | 386.3 | 386.3 | 386.3 | | | Included | C | Gosh *et al.* 1990 |
| Ceriodaphnia reticulata | cladoceran | 50 | 5.2 | 5.2 | | | | Included | C | Elnabarawy *et al.*, 1986 |
| Ceriodaphnia reticulata | cladoceran | 45 | 17 | 18.8 | 9.9 | | | Included | C | Mount & Norberg 1984 |
| Ceriodaphnia dubia | cladoceran | 97.6 | 14 | 7.5 | | | | Included | C | Belanger and Cherry 1990 |
| Ceriodaphnia dubia | cladoceran | 97.6 | 28 | 14.9 | | | | Included | C | Belanger and Cherry 1990 |
| Ceriodaphnia dubia | cladoceran | 97.6 | 31 | 16.5 | | | | Included | C | Belanger and Cherry 1990 |
| Ceriodaphnia dubia | cladoceran | 113.6 | 52 | 24.0 | | | | Included | C | Belanger and Cherry 1990 |
| Ceriodaphnia dubia | cladoceran | 113.6 | 76 | 35.1 | | | | Included | C | Belanger and Cherry 1990 |

# Table IX.8-1
## Copper Toxicity Database (Continued)

| Species | Common name | Hardness | LC50 | | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Reported | Adjusted to Hardness of 50 mg/L | | | | | | |
| Ceriodaphnia dubia | cladoceran | 113.6 | 91 | 42.0 | | | | Included | C | Belanger and Cherry 1990 |
| Ceriodaphnia dubia | cladoceran | 182 | 56 | 16.6 | | | | Included | C | Belanger and Cherry 1990 |
| Ceriodaphnia dubia | cladoceran | 182 | 84 | 24.9 | | | | Included | C | Belanger and Cherry 1990 |
| Ceriodaphnia dubia | cladoceran | 182 | 93 | 27.5 | | | | Included | C | Belanger and Cherry 1990 |
| Ceriodaphnia dubia | cladoceran | 90 | 13.4 | 7.7 | | | | Included | C | Oris *et al.*, 1991 |
| Ceriodaphnia dubia | cladoceran | 87.5 | 11.25 | 6.6 | | | | Included | C | Neserke 1994 |
| Ceriodaphnia dubia | cladoceran | 80.8 | 13.17 | 8.4 | | | | Included | C | Neserke 1994 |
| Ceriodaphnia dubia | cladoceran | 80.8 | 25.25 | 16.1 | | | | Included | C | Neserke 1994 |
| Ceriodaphnia dubia | cladoceran | 60 | 11.25 | 9.5 | | | | Included | C | Neserke 1994 |
| Ceriodaphnia dubia | cladoceran | 30 | 4.5 | 7.3 | | | | Included | C | Neserke 1994 |
| Ceriodaphnia dubia | cladoceran | 188 | 36.6 | 10.5 | | | | Included | C | Bright 1995 |
| Ceriodaphnia dubia | cladoceran | 204 | 19.1 | 5.1 | | | | Included | C | Bright 1995 |
| Ceriodaphnia dubia | cladoceran | 428 | 36.4 | 4.8 | | | | Included | C | Bright 1995 |
| Ceriodaphnia dubia | cladoceran | 410 | 11.7 | 1.6 | | | | Included | C | Bright 1995 |
| Ceriodaphnia dubia | cladoceran | 194 | 12.3 | 3.4 | | | | Included | C | Bright 1995 |
| Ceriodaphnia dubia | cladoceran | 440 | 12 | 1.5 | | | | Included | C | Bright 1995 |
| Ceriodaphnia dubia | cladoceran | 80 | 6.98 | 4.5 | | | | Included | C | Diamond *et al.*, 1997 |
| Ceriodaphnia dubia | cladoceran | 99 | 10.1 | 5.3 | | | | Included | C | Tetra Tech, 1998 |
| Ceriodaphnia dubia | cladoceran | 70 | 14.65 | 10.7 | | | | Included | C | Tetra Tech, 1998 |
| Ceriodaphnia dubia | cladoceran | 74 | 6.72 | 4.6 | | | | Included | C | Tetra Tech, 1998 |
| Ceriodaphnia dubia | cladoceran | 72 | 6.59 | 4.7 | | | | Included | C | Tetra Tech, 1998 |
| Ceriodaphnia dubia | cladoceran | 148 | 23.3 | 8.4 | | | | Included | C | Tetra Tech, 1998 |
| Ceriodaphnia dubia | cladoceran | 148 | 24.99 | 9.0 | | | | Included | C | Tetra Tech, 1998 |
| Ceriodaphnia dubia | cladoceran | 142 | 18.91 | 7.1 | | | | Included | C | Tetra Tech, 1998 |
| Ceriodaphnia dubia | cladoceran | 144 | 73.5 | 27.1 | | | | Included | C | Tetra Tech, 1998 |

# Table IX.8-1
## Copper Toxicity Database (Continued)

| Species | Common name | Hardness | LC50 | | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Reported | Adjusted to Hardness of 50 mg/L | | | | | | |
| Ceriodaphnia dubia | cladoceran | 148 | 18.48 | 6.6 | | | | Included | C | Tetra Tech, 1998 |
| Ceriodaphnia dubia | cladoceran | 200 | 31.77 | 8.6 | | | | Included | C | Tetra Tech, 1998 |
| Ceriodaphnia dubia | cladoceran | 193 | 58.82 | 16.5 | | | | Included | C | Tetra Tech, 1998 |
| Ceriodaphnia dubia | cladoceran | 198 | 31.53 | 8.6 | | | | Included | C | Tetra Tech, 1998 |
| Ceriodaphnia dubia | cladoceran | 194 | 39.38 | 11.0 | | | | Included | C | Tetra Tech, 1998 |
| Ceriodaphnia dubia | cladoceran | 78 | 13.1 | 8.6 | | | | Included | C | Diamond 2000 |
| Ceriodaphnia dubia | cladoceran | 90 | 8.88 | 5.1 | | | | Included | C | Diamond 2000 |
| Ceriodaphnia dubia | cladoceran | 90 | 10.3 | 5.9 | 8.9 | | | Included | C | Diamond 2000 |
| Daphnia ambigua | cladoceran | 50 | 24.8 | 24.8 | 24.8 | | | Included | C | Winner and Farrel 1976 |
| Daphnia magna | cladoceran | | 12.7 | | | | | Excluded | E | Anderson 1948 |
| Daphnia magna | cladoceran | 226 | 200 | 48.3 | | | | Excluded | E | Cabjszek & Stasiak 1960 |
| Daphnia magna | cladoceran | 45.3 | 9.8 | 10.8 | | | | Excluded | E | Blesinger & Christensen 1972 |
| Daphnia magna | cladoceran | 99 | 85 | 44.7 | | | | Excluded | E | Adema & Degroot-Van Zijl 1972 |
| Daphnia magna | cladoceran | 99 | 50 | 26.3 | | | | Excluded | E | Adema & Degroot-Van Zijl 1972 |
| Daphnia magna | cladoceran | 52 | 26 | 25.1 | | 13.40 | 1.9 | Included | A | Chapman *et al.* Manuscript |
| Daphnia magna | cladoceran | 105 | 30 | 14.9 | | 15.69 | 1.0 | Included | A | Chapman *et al.* Manuscript |
| Daphnia magna | cladoceran | 106 | 38 | 18.7 | | | | Excluded | E | Chapman *et al.* Manuscript |
| Daphnia magna | cladoceran | 207 | 69 | 18.1 | | 2.8 | 6.5 | Included | A | Chapman *et al.* Manuscript |
| Daphnia magna | cladoceran | 45 | 10 | 11.0 | | | | Excluded | E | Cairns *et al.* 1978 |
| Daphnia magna | cladoceran | 100 | 31.8 | 16.5 | | | | Excluded | E | Borgmann & Ralph 1983 |
| Daphnia magna | cladoceran | 143 | 26 | 9.7 | | | | Excluded | E | Lewis 1983 |
| Daphnia magna | cladoceran | 250 | 6.5 | 1.4 | | | | Excluded | E | Dave 1984 |
| Daphnia magna | cladoceran | 45 | 54 | 59.6 | | | | Excluded | E | Mount & Norberg 1984 |
| Daphnia magna | cladoceran | 240 | 41 | 9.4 | | | | Excluded | E | Elnabarawy *et al.*, 1986 |
| Daphnia magna | cladoceran | 54 | 7 | 6.5 | | | | Excluded | E | Nebeker *et al.*, 1986 |

# Table IX.8-1
## Copper Toxicity Database (Continued)

| Species | Common name | Hardness | LC50 | | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Reported | Adjusted to Hardness of 50 mg/L | | | | | | |
| Daphnia magna | cladoceran | 80 | 10 | 6.4 | | | | Excluded | E | Nebeker *et al.*, 1986 |
| Daphnia magna | cladoceran | 80 | 6 | 3.9 | | | | Excluded | E | Nebeker *et al.*, 1986 |
| Daphnia magna | cladoceran | 80 | 14 | 9.0 | | | | Excluded | E | Nebeker *et al.*, 1986 |
| Daphnia magna | cladoceran | 80 | 7 | 4.5 | | | | Excluded | E | Nebeker *et al.*, 1986 |
| Daphnia magna | cladoceran | 80 | 10 | 6.4 | | | | Excluded | E | Nebeker *et al.*, 1986 |
| Daphnia magna | cladoceran | 80 | 18 | 11.6 | | | | Excluded | E | Nebeker *et al.*, 1986 |
| Daphnia magna | cladoceran | 240 | 93 | 21.2 | | | | Excluded | E | Khangarot and ray 1989 |
| Daphnia magna | cladoceran | 10 | 21.5 | 98.0 | | | | Excluded | E | Hickey and Vickers 1992 |
| Daphnia magna | cladoceran | 33.8 | 11.5 | 16.6 | | | | Excluded | E | Koivisto *et al.*, 1992 |
| Daphnia magna | cladoceran | 50 | 7 | 7.0 | | | | Excluded | E | Oikari *et al.*, 1992 |
| Daphnia magna | cladoceran | 170 | 41.2 | 13.0 | | | | Excluded | E | Baird *et al.*, 1991 |
| Daphnia magna | cladoceran | 170 | 10.5 | 3.3 | | | | Excluded | E | Baird *et al.*, 1991 |
| Daphnia magna | cladoceran | 170 | 20.6 | 6.5 | | | | Excluded | E | Baird *et al.*, 1991 |
| Daphnia magna | cladoceran | 170 | 17.3 | 5.5 | | | | Excluded | E | Baird *et al.*, 1991 |
| Daphnia magna | cladoceran | 170 | 70.7 | 22.3 | | | | Excluded | E | Baird *et al.*, 1991 |
| Daphnia magna | cladoceran | 170 | 31.3 | 9.9 | | | | Excluded | E | Baird *et al.*, 1991 |
| Daphnia magna | cladoceran | 100 | 7.1 | 3.7 | | | | Excluded | E | Meador 1991 |
| Daphnia magna | cladoceran | 100 | 18.7 | 9.7 | | | | Excluded | E | Meador 1991 |
| Daphnia magna | cladoceran | 100 | 18.9 | 9.8 | | | | Excluded | E | Meador 1991 |
| Daphnia magna | cladoceran | 170 | 31 | 9.8 | | | | Excluded | E | Lazorchak and Waller 1993 |
| Daphnia magna | cladoceran | 170 | 38 | 12.0 | | | | Excluded | E | Lazorchak and Waller 1993 |
| Daphnia magna | cladoceran | 170 | 35 | 11.0 | | | | Excluded | E | Lazorchak and Waller 1993 |
| Daphnia magna | cladoceran | 170 | 58 | 18.3 | | | | Excluded | E | Lazorchak and Waller 1993 |
| Daphnia magna | cladoceran | 170 | 37 | 11.7 | | | | Excluded | E | Lazorchak and Waller 1993 |
| Daphnia magna | cladoceran | 170 | 51 | 16.1 | | | | Excluded | E | Lazorchak and Waller 1993 |

# Table IX.8-1
## Copper Toxicity Database (Continued)

| Species | Common name | Hardness | LC50 | | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Reported | Adjusted to Hardness of 50 mg/L | | | | | | |
| Daphnia magna | cladoceran | 170 | 39 | 12.3 | | | | Excluded | E | Lazorchak and Waller 1993 |
| Daphnia magna | cladoceran | 170 | 50 | 15.8 | | | | Excluded | E | Lazorchak and Waller 1993 |
| Daphnia magna | cladoceran | 170 | 52 | 16.4 | | | | Excluded | E | Lazorchak and Waller 1993 |
| Daphnia magna | cladoceran | 170 | 31 | 9.8 | | | | Excluded | E | Lazorchak and Waller 1993 |
| Daphnia magna | cladoceran | 170 | 30 | 9.5 | | | | Excluded | E | Lazorchak and Waller 1993 |
| Daphnia magna | cladoceran | 170 | 46 | 14.5 | | | | Excluded | E | Lazorchak and Waller 1993 |
| Daphnia magna | cladoceran | 170 | 63 | 19.9 | | | | Excluded | E | Lazorchak and Waller 1993 |
| Daphnia magna | cladoceran | 72 | 4.8 | 3.4 | | | | Excluded | E | Diamond 2000 |
| Daphnia magna | cladoceran | 76 | 6.24 | 4.2 | | | | Excluded | E | Diamond 2000 |
| Daphnia magna | cladoceran | 80 | 6.17 | 4.0 | | | | Excluded | E | Diamond 2000 |
| Daphnia magna | cladoceran | 72 | 6.62 | 4.7 | | | | Excluded | E | Diamond 2000 |
| Daphnia magna | cladoceran | 84 | 10.2 | 6.3 | | | | Excluded | E | Diamond 2000 |
| Daphnia magna | cladoceran | 84 | 10.8 | 6.6 | | | | Excluded | E | Diamond 2000 |
| Daphnia magna | cladoceran | 44 | 4.6 | 5.2 | | | | Excluded | E | Diamond 2000 |
| Daphnia magna | cladoceran | 44 | 7.8 | 8.8 | | | | Excluded | E | Diamond 2000 |
| Daphnia magna | cladoceran | 36 | 3 | 4.1 | | | | Excluded | E | Diamond 2000 |
| Daphnia magna | cladoceran | 76 | 10.4 | 7.0 | | | | Excluded | E | Diamond 2000 |
| Daphnia magna | cladoceran | 88 | 16.9 | 9.9 | 10.4 | | | Excluded | E | Diamond 2000 |
| Daphnia parvula | cladoceran | 50 | 26.4 | 26.4 | 26.4 | | | Included | C | Diamond 2000 |
| Daphnia pulex | cladoceran | 45 | 10 | 11.0 | | | | Included | C | Cairns *et al.* 1978 |
| Daphnia pulex | cladoceran | 45 | 53 | 58.5 | 25.4 | | | Included | C | Mount & Norberg 1984 |
| Daphnia pulicaria | cladoceran | 48 | 11.4 | 11.8 | | | | Included | C | Lind *et al.* Manuscript |
| Daphnia pulicaria | cladoceran | 48 | 9.06 | 9.4 | | | | Included | C | Lind *et al.* Manuscript |
| Daphnia pulicaria | cladoceran | 48 | 7.24 | 7.5 | | | | Included | C | Lind *et al.* Manuscript |
| Daphnia pulicaria | cladoceran | 44 | 10.8 | 12.2 | | | | Included | C | Lind *et al.* Manuscript |

# Table IX.8-1
# Copper Toxicity Database (Continued)

| Species | Common name | Hardness | LC50 | | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Reported | Adjusted to Hardness of 50 mg/L | | | | | | |
| Daphnia pulicaria | cladoceran | 45 | 9.3 | 10.3 | | | | Included | C | Lind *et al.* Manuscript |
| Daphnia pulicaria | cladoceran | 95 | 17.8 | 9.7 | | | | Included | C | Lind *et al.* Manuscript |
| Daphnia pulicaria | cladoceran | 145 | 23.7 | 8.7 | | | | Included | C | Lind *et al.* Manuscript |
| Daphnia pulicaria | cladoceran | 245 | 27.3 | 6.1 | 9.3 | | | Included | C | Lind *et al.* Manuscript |
| Daphnia rosea | cladoceran | 50 | 69 | 69.0 | 69.0 | | | Included | C | Lalande and Pinel-Alloul 1984 |
| Moina dubia | cladoceran | 50 | 19.2 | 19.2 | 19.2 | | | Included | C | Ghosh *et al.* 1990 |
| Gammarus pseudolimnaeus | amphipod | 45 | 20 | 22.1 | 22.1 | 6.7 | 3.3 | Included | A | Arthur & Leonard 1970 |
| Gammarus pulex | amphipod | 104 | 41 | 20.6 | | | | Included | A | Stephenson 1983 |
| Gammarus pulex | amphipod | 249 | 183 | 40.3 | 28.8 | | | Included | A | Stephenson 1983 |
| Gammarus sp. | amphipod | 50 | 910 | 910.0 | | | | Excluded | G | Rehwoldt *et al.* 1973 |
| Crangonyx pseudogracilis | amphipod | 50 | 1290 | 1290.0 | 1290.0 | | | Included | C | Martin and Holdich 1986 |
| Echinogammarus berilloni | amphipod | 50 | 75.7 | 75.7 | 75.7 | | | Included | C | Vincent *et al.* 1986 |
| Craterocephalus margoriae | Marjorie's hardihead | 50 | 182.2 | 182.2 | 182.2 | | | Excluded | D | Skidmore and Firth 1983 |
| Orconectes limosus | crayfish | | 600 | | | | | Excluded | D | Boutet & Chasemartin 1973 |
| Orconectes rusticus | crayfish | 112 | 3000 | 1403.2 | 1403.2 | | | Excluded | D | Hubschman 1967 |
| Procambarus clarkii (larva) | crayfish | 17 | 720 | 1989.6 | 1989.6 | | | Excluded | D | Rice & Harrison 1983 |
| Macrobrachium sp. | prawn | 50 | 204.4 | 204.4 | 204.4 | | | Excluded | D | Skidmore and Firth 1983 |
| Unidentified | damselfly | 50 | 4600 | 4600.0 | 4600.0 | | | Included | C | Rehwoldt *et al.* 1973 |
| Acroneuria lycorias | stonefly | 40 | 8300 | 10242.0 | 10242.0 | | | Included | C | Warnick & Bell 1969 |
| Unidentified | caddisfly | 50 | 6200 | 6200.0 | 6200.0 | | | Excluded | G | Rehwoldt *et al.* 1973 |
| Clisttornia magnifica | caddisfly | | | | | 18.2 | | Included | C | Nebeker *et al.* 1964 |

# Table IX.8-1
# Copper Toxicity Database (Continued)

| Species | Common name | Hardness | LC50 | | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Reported | Adjusted to Hardness of 50 mg/L | | | | | | |
| Chironomus tentans (1st instar) | midge | 78 | 298 | 196.0 | | | | Included | A | Nebeker *et al.* 1984a |
| Chironomus tentans (2nd instar) | midge | 78 | 773 | 508.4 | | | | Included | A | Nebeker *et al.* 1984a |
| Chironomus tentans (3rd instar) | midge | 78 | 1446 | 951.1 | | | | Included | A | Nebeker *et al.* 1984a |
| Chironomus tentans (4th instar) | midge | 78 | 1690 | 1111.5 | | | | Included | A | Nebeker *et al.* 1984a |
| Chironomus tentans | midge | 50 | 197.2 | 197.2 | 460.8 | | | Included | A | Nebeker *et al.* 1964 |
| Chironomus sp. | midge | 50 | 30 | 30.0 | | | | Excluded | G | Rehwoldt *et al.* 1973 |
| Chironomus decorus | midge | 50 | 833.6 | 833.6 | 833.6 | | | Included | C | Kosalwat and Knight 1987 |
| Chironomus riparius | midge | 50 | 247.1 | 247.1 | 247.1 | | | Included | C | Taylor *et al.* 1991 |
| Pectinatella magnifca | bryozoan | 205 | 510 | 135.0 | 135.0 | | | Excluded | D | Pardue and Wood 1980 |
| Lophopodella carteri | bryozoan | 205 | 140 | 37.0 | | | | Excluded | D | Pardue and Wood 1980 |
| Lophopodella carteri | bryozoan | 50 | 135 | 135.0 | 70.7 | | | Excluded | D | Pardue and Wood 1980 |
| Plumatella emarginata | bryozoan | 205 | 140 | 37.0 | 37.0 | | | Excluded | D | Pardue and Wood 1980 |
| Anguilla rostrata | american eel | 53 | 6400 | 6058.1 | | | | Excluded | D | Rehwoldt *et al.* 1971 |
| Anguilla rostrata | american eel | 55 | 6000 | 5484.7 | | | | Excluded | D | Rehwoldt *et al.* 1972 |
| Anguilla rostrata (black eel stage) | american eel | 44 | 3200 | 3609.6 | | | | Excluded | D | Hinton & Eversole 1979 |
| Anguilla rostrata (glass eel stage) | american eel | 44 | 2540 | 2865.1 | 4305.5 | | | Excluded | D | Hinton & Eversole 1979 |
| Oncorhyncus kisutch (adult) | coho salmon | 20 | 46 | 109.1 | | | | Excluded | D | Chapman & Stevens 1978 |
| Oncorhyncus kisutch (parr) | coho salmon | 23 | 32.6 | 67.8 | | | | Excluded | D | Chapman 1975 |
| Oncorhyncus kisutch (adult) | coho salmon | 23 | 42.9 | 89.2 | | | | Excluded | D | Chapman 1975 |

# Table IX.8-1
## Copper Toxicity Database (Continued)

| Species | Common name | Hardness | LC50 | | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Reported | Adjusted to Hardness of 50 mg/L | | | | | | |
| Oncorhyncus kisutch (yearling) | coho salmon | 94 | 74 | 40.8 | | | | Included | B | Lorz & McPherson 1976 |
| Oncorhyncus kisutch (yearling) | coho salmon | 94 | 70 | 38.6 | | | | Included | B | Lorz & McPherson 1976 |
| Oncorhyncus kisutch (smolt) | coho salmon | 94 | 60 | 33.1 | 33.1 | | | Included | B | Lorz & McPherson 1976 |
| Oncorhyncus kisutch (juvenile) | coho salmon | 33 | 164 | 242.6 | | | | Excluded | F | Buckley 1983 |
| Oncorhynchus nerka (smolt) | sockeye salmon | 41 | 240 | 289.3 | | | | Included | B | Davis & Shand 1978 |
| Oncorhynchus nerka (smolt) | sockeye salmon | 41 | 103 | 124.2 | | | | Included | B | Davis & Shand 1978 |
| Oncorhynchus nerka (fingerling) | sockeye salmon | 41 | 220 | 265.2 | | | | Included | B | Davis & Shand 1978 |
| Oncorhynchus nerka (fingerling) | sockeye salmon | 41 | 210 | 253.2 | | | | Included | B | Davis & Shand 1978 |
| Oncorhynchus nerka (fingerling) | sockeye salmon | 41 | 240 | 289.3 | 233.8 | | | Included | B | Davis & Shand 1978 |
| Oncorhynchus tshawtscha (alevin) | chinook salmon | 23 | 26 | 54.0 | | | | Included | B | Chapman 1975, 1978 |
| Oncorhynchus tshawtscha (swim-up) | chinook salmon | 23 | 19 | 39.5 | | | | Included | B | Chapman 1975, 1978 |
| Oncorhynchus tshawtscha (parr) | chinook salmon | 23 | 38 | 79.0 | | | | Included | B | Chapman 1975, 1978 |
| Oncorhynchus tshawtscha (smolt) | chinook salmon | 23 | 26 | 54.0 | | | | Included | B | Chapman 1975, 1978 |
| Oncorhynchus tshawtscha (juvenile) | chinook salmon | 25 | 33.1 | 63.6 | | | | Included | B | Chapman 1982 |
| Oncorhynchus | chinook salmon | 13 | 10 | 35.6 | | | | Included | B | Chapman & McCrady 1977 |

# Table IX.8-1
# Copper Toxicity Database (Continued)

| Species | Common name | Hardness | LC50 | | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Reported | Adjusted to Hardness of 50 mg/L | | | | | | |
| tshawtscha | | | | | | | | | | |
| Oncorhynchus tshawtscha | chinook salmon | 46 | 22 | 23.8 | | | | Included | B | Chapman & McCrady 1977 |
| Oncorhynchus tshawtscha | chinook salmon | 182 | 85 | 25.2 | | | | Included | B | Chapman & McCrady 1977 |
| Oncorhynchus tshawtscha | chinook salmon | 359 | 130 | 20.3 | | | | Included | B | Chapman & McCrady 1977 |
| Oncorhynchus tshawtscha | chinook salmon | 21 | 32 | 72.5 | 42.3 | | | Included | B | Finlayson & Verrue 1982 |
| Salmo clarki | cutthroat trout | 205 | 367 | 97.1 | | | | Included | B | Chakoumakos et al 1979 |
| Salmo clarki | cutthroat trout | 70 | 186 | 135.5 | | | | Included | B | Chakoumakos et al 1979 |
| Salmo clarki | cutthroat trout | 18 | 36.8 | 96.4 | | | | Included | B | Chakoumakos et al 1979 |
| Salmo clarki | cutthroat trout | 204 | 232 | 61.7 | | | | Included | B | Chakoumakos et al 1979 |
| Salmo clarki | cutthroat trout | 83 | 162 | 100.5 | | | | Included | B | Chakoumakos et al 1979 |
| Salmo clarki | cutthroat trout | 31 | 73.6 | 115.5 | | | | Included | B | Chakoumakos et al 1979 |
| Salmo clarki | cutthroat trout | 160 | 91 | 30.4 | | | | Included | B | Chakoumakos et al 1979 |
| Salmo clarki | cutthroat trout | 74 | 44.4 | 30.7 | | | | Included | B | Chakoumakos et al 1979 |
| Salmo clarki | cutthroat trout | 26 | 15.7 | 29.1 | 66.3 | | | Included | B | Chakoumakos et al 1979 |
| Oncorhynchus mykiss | rainbow trout | 30 | 19.9 | 32.2 | | | | Excluded | F | Howarth & Sprague 1978 |
| Oncorhynchus mykiss | rainbow trout | 32 | 22.4 | 34.1 | | | | Excluded | F | Howarth & Sprague 1978 |
| Oncorhynchus mykiss | rainbow trout | 31 | 28.9 | 45.3 | | | | Excluded | F | Howarth & Sprague 1978 |
| Oncorhynchus mykiss | rainbow trout | 31 | 30 | 47.1 | | | | Excluded | F | Howarth & Sprague 1978 |
| Oncorhynchus mykiss | rainbow trout | 30 | 30 | 48.5 | | | | Excluded | F | Howarth & Sprague 1978 |
| Oncorhynchus mykiss | rainbow trout | 101 | 176 | 90.7 | | | | Excluded | F | Howarth & Sprague 1978 |
| Oncorhynchus mykiss | rainbow trout | 101 | 40 | 20.6 | | | | Excluded | F | Howarth & Sprague 1978 |
| Oncorhynchus mykiss | rainbow trout | 99 | 33.1 | 17.4 | | | | Excluded | F | Howarth & Sprague 1978 |

# Table IX.8-1
# Copper Toxicity Database (Continued)

| Species | Common name | Hardness | LC50 | | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Reported | Adjusted to Hardness of 50 mg/L | | | | | | |
| Oncorhynchus mykiss | rainbow trout | 102 | 30.7 | 15.7 | | | | Excluded | F | Howarth & Sprague 1978 |
| Oncorhynchus mykiss | rainbow trout | 101 | 46.3 | 23.9 | | | | Excluded | F | Howarth & Sprague 1978 |
| Oncorhynchus mykiss | rainbow trout | 99 | 47.9 | 25.2 | | | | Excluded | F | Howarth & Sprague 1978 |
| Oncorhynchus mykiss | rainbow trout | 100 | 48.1 | 25.0 | | | | Excluded | F | Howarth & Sprague 1978 |
| Oncorhynchus mykiss | rainbow trout | 100 | 81.1 | 42.2 | | | | Excluded | F | Howarth & Sprague 1978 |
| Oncorhynchus mykiss | rainbow trout | 98 | 85.9 | 45.6 | | | | Excluded | F | Howarth & Sprague 1978 |
| Oncorhynchus mykiss | rainbow trout | 370 | 232 | 35.2 | | | | Excluded | F | Howarth & Sprague 1978 |
| Oncorhynchus mykiss | rainbow trout | 366 | 70 | 10.7 | | | | Excluded | F | Howarth & Sprague 1978 |
| Oncorhynchus mykiss | rainbow trout | 371 | 82.2 | 12.4 | | | | Excluded | F | Howarth & Sprague 1978 |
| Oncorhynchus mykiss | rainbow trout | 361 | 298 | 46.3 | | | | Excluded | F | Howarth & Sprague 1978 |
| Oncorhynchus mykiss | rainbow trout | 194 | 169 | 47.1 | | | | Excluded | F | Chakoumakos et al 1979 |
| Oncorhynchus mykiss | rainbow trout | 194 | 85.3 | 23.8 | | | | Excluded | F | Chakoumakos et al 1979 |
| Oncorhynchus mykiss | rainbow trout | 194 | 83.3 | 23.2 | | | | Excluded | F | Chakoumakos et al 1979 |
| Oncorhynchus mykiss | rainbow trout | 194 | 103 | 28.7 | | | | Excluded | F | Chakoumakos et al 1979 |
| Oncorhynchus mykiss | rainbow trout | 194 | 274 | 76.4 | | | | Excluded | F | Chakoumakos et al 1979 |
| Oncorhynchus mykiss | rainbow trout | 194 | 128 | 35.7 | | | | Excluded | F | Chakoumakos et al 1979 |
| Oncorhynchus mykiss | rainbow trout | 194 | 221 | 61.6 | | | | Excluded | F | Chakoumakos et al 1979 |
| Oncorhynchus mykiss | rainbow trout | 194 | 165 | 46.0 | | | | Excluded | F | Chakoumakos et al 1979 |
| Oncorhynchus mykiss | rainbow trout | 194 | 197 | 54.9 | | | | Excluded | F | Chakoumakos et al 1979 |
| Oncorhynchus mykiss | rainbow trout | 194 | 514 | 143.3 | | | | Excluded | F | Chakoumakos et al 1979 |
| Oncorhynchus mykiss | rainbow trout | 194 | 243 | 67.7 | | | | Excluded | F | Chakoumakos et al 1979 |
| Oncorhynchus mykiss (alevin) | rainbow trout | 23 | 28 | 58.2 | | | | Excluded | F | Chapman 1975, 1978 |
| Oncorhynchus mykiss (swim-up) | rainbow trout | 23 | 17 | 35.3 | | | | Excluded | F | Chapman 1975, 1978 |
| Oncorhynchus mykiss | rainbow trout | 23 | 18 | 37.4 | | | | Excluded | F | Chapman 1975, 1978 |

# Table IX.8-1
# Copper Toxicity Database (Continued)

| Species | Common name | Hardness | LC50 | | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Reported | Adjusted to Hardness of 50 mg/L | | | | | | |
| (parr) | | | | | | | | | | |
| Oncorhynchus mykiss (smolt) | rainbow trout | 23 | 29 | 60.3 | | | | Excluded | F | Chapman 1975, 1978 |
| Oncorhynchus mykiss (adult) | rainbow trout | 42 | 57 | 67.2 | | | | Excluded | F | Chapman 1975; Chapman & Stevens 1978 |
| Oncorhynchus mykiss (fry) | rainbow trout | | 253 | | | | | Excluded | F | Hale 1977 |
| Oncorhynchus mykiss | rainbow trout | 125 | 200 | 84.4 | | | | Excluded | F | Spear 1977; Anderson & Spear 1980b |
| Oncorhynchus mykiss | rainbow trout | 125 | 190 | 80.1 | | | | Excluded | F | Spear 1977; Anderson & Spear 1980b |
| Oncorhynchus mykiss | rainbow trout | 125 | 210 | 88.6 | | | | Excluded | F | Spear 1977; Anderson & Spear 1980b |
| Oncorhynchus mykiss | rainbow trout | 290 | 890 | 169.9 | | | | Excluded | F | Calamari & Marchetti 1973 |
| Oncorhynchus mykiss | rainbow trout | 90 | 190 | 109.2 | | | | Excluded | F | Giles & Klaverkamp 1982 |
| Oncorhynchus mykiss | rainbow trout | 120 | 80 | 35.1 | 42.5 | | | Excluded | F | Seim *et al.* 1984 |
| Oncorhynchus mykiss | rainbow trout | | | | | 20.6 | | Included | B | McKim *et al.* 1978 |
| Salmo salar | atlantic salmon | 20 | 48 | 113.8 | | | | Included | B | Sprague 1964 |
| Salmo salar | atlantic salmon | 9 | 125 | 628.9 | | | | Included | B | Wilson 1972 |
| Salmo salar | atlantic salmon | 14 | 32 | 106.2 | 196.6 | | | Included | B | Sprague & Ramsey 1965 |
| Salvelinus fontinalis | brook trout | 45 | 100 | 110.4 | 110.4 | 14.1 | 7.8 | Included | B | McKim & Benoit 1971 |
| Salvelinus fontinalis | brook trout | | | | | 33.8 | | Included | B | McKim *et al.* 1978 |
| Salvelinus fontinalis | brook trout | | | | | 5.0 | | Included | B | Sauter *et al.* 1976 |
| Salmo trutta | brown trout | | | | | 36.3 | | Included | B | McKim *et al.* 1978 |
| Salvelinus namaycush | lake trout | | | | | 33.1 | | Included | A | McKim *et al.* 1978 |
| Denariusa bandata | penny fish | 50 | 120.8 | 120.8 | 120.8 | | | Excluded | D | Williams *et al.* 1981 |
| Esox lucius | northern pike | | | | | 65.5 | | Included | A | McKim *et al.* 1978 |

# Table IX.8-1
## Copper Toxicity Database (Continued)

| Species | Common name | Hardness | LC50 | | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Reported | Adjusted to Hardness of 50 mg/L | | | | | | |
| Catostomus commersoni | white sucker | | | | | 22.7 | | Included | A | McKim *et al.* 1978 |
| Acrocheilus alutaceus | chiselmouth | 54 | 143 | 133.0 | 133.0 | | | Excluded | D | Andros & Garton 1980 |
| Campostoma anomalum | central stoneroller | 200 | 290 | 78.5 | 78.5 | | | Excluded | D | Geckler *et al.* 1976 |
| Carassius auratus | goldfish | 20 | 36 | 85.4 | | | | Excluded | D | Pickering & Henderson 1966 |
| Carassius auratus | goldfish | 52 | 300 | 289.1 | 157.1 | | | Excluded | D | Tsai & McKee 1978, 1980 |
| Melanotaenia splendida splendida | chequered rainbowfish | 50 | 186 | 186.0 | 186.0 | | | Excluded | D | Skidmore and Firth 1983 |
| Cyprinus carpio | common carp | 53 | 810 | 766.7 | | | | Excluded | D | Rehwoldt *et al.* 1971 |
| Cyprinus carpio | common carp | 55 | 800 | 731.3 | | | | Excluded | D | Rehwoldt *et al.* 1972 |
| Cyprinus carpio (140 mg) | common carp | 166 | 117.5 | 37.9 | | | | Excluded | D | Deshmukh & Marathe 1980 |
| Cyprinus carpio (3200 mg) | common carp | 166 | 530 | 171.1 | | | | Excluded | D | Deshmukh & Marathe 1980 |
| Cyprinus carpio | common carp | 19 | 63 | 156.8 | 224.5 | | | Excluded | D | Khangarot *et al.* 1983 |
| Notropis chrysocephalus | striped shiner | 200 | 790 | 214.0 | | | | Excluded | D | Geckler *et al.* 1976 |
| Notropis chrysocephalus | striped shiner | 200 | 1900 | 514.6 | 331.8 | | | Excluded | D | Deshmukh & Marathe 1980 |
| Pimephales notatus | bluntnose minnow | 200 | 290 | 78.5 | | | | Excluded | D | Geckler *et al.* 1976 |
| Pimephales notatus | bluntnose minnow | 200 | 260 | 70.4 | | | | Excluded | D | Geckler *et al.* 1976 |
| Pimephales notatus | bluntnose minnow | 200 | 260 | 70.4 | | | | Excluded | D | Geckler *et al.* 1976 |
| Pimephales notatus | bluntnose minnow | 200 | 280 | 75.8 | | | | Excluded | D | Geckler *et al.* 1976 |
| Pimephales notatus | bluntnose minnow | 200 | 340 | 92.1 | | | | Excluded | D | Geckler *et al.* 1976 |
| Pimephales notatus | bluntnose | 194 | 210 | 58.5 | | | | Excluded | D | Horing & Neiheisen 1979 |

# Table IX.8-1
## Copper Toxicity Database (Continued)

| Species | Common name | Hardness | LC50 | | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Reported | Adjusted to Hardness of 50 mg/L | | | | | | |
| | minnow | | | | | | | | | |
| Pimephales notatus | bluntnose minnow | 194 | 220 | 61.3 | | | | Excluded | D | Horing & Neiheisen 1979 |
| Pimephales notatus | bluntnose minnow | 194 | 270 | 75.3 | 72.2 | | | Excluded | D | Horing & Neiheisen 1979 |
| Pimephales promelas | fathead minnow | 20 | 50 | 118.6 | | | | Excluded | D | Tarzwell & Hendersen 1960 |
| Pimephales promelas | fathead minnow | 400 | 1400 | 197.3 | | | | Excluded | D | Tarzwell & Hendersen 1960 |
| Pimephales promelas | fathead minnow | 202 | 460 | 123.4 | | | | Excluded | D | Pickering *et al.* 1977 |
| Pimephales promelas | fathead minnow | 202 | 490 | 131.5 | | | | Excluded | D | Pickering *et al.* 1977 |
| Pimephales promelas | fathead minnow | 200 | 790 | 214.0 | | | | Excluded | D | Andrew 1976 |
| Pimephales promelas | fathead minnow | 45 | 200 | 220.9 | | | | Excluded | D | Andrew 1976 |
| Pimephales promelas | fathead minnow | 20 | 25 | 59.3 | | | | Excluded | D | Pickering & Henderson 1966 |
| Pimephales promelas | fathead minnow | 20 | 23 | 54.5 | | | | Excluded | D | Pickering & Henderson 1966 |
| Pimephales promelas | fathead minnow | 20 | 23 | 54.5 | | | | Excluded | D | Pickering & Henderson 1966 |
| Pimephales promelas | fathead minnow | 20 | 22 | 52.2 | | | | Excluded | D | Pickering & Henderson 1966 |
| Pimephales promelas | fathead minnow | 360 | 1760 | 274.0 | | | | Excluded | D | Pickering & Henderson 1966 |
| Pimephales promelas | fathead minnow | 360 | 1140 | 177.5 | | | | Excluded | D | Pickering & Henderson 1966 |
| Pimephales promelas | fathead minnow | 200 | 430 | 116.5 | | | | Excluded | D | Mount 1968 |
| Pimephales promelas | fathead minnow | 200 | 470 | 127.3 | | | | Excluded | D | Mount 1968 |
| Pimephales promelas | fathead minnow | 31 | 84 | 131.8 | | | | Excluded | D | Mount & Stephan 1969 |
| Pimephales promelas | fathead minnow | 31 | 75 | 117.7 | | | | Excluded | D | Mount & Stephan 1969 |
| Pimephales promelas | fathead minnow | 200 | 440 | 119.2 | | | | Excluded | D | Geckler *et al.* 1976 |
| Pimephales promelas | fathead minnow | 200 | 490 | 132.7 | | | | Excluded | D | Geckler *et al.* 1976 |
| Pimephales promelas | fathead minnow | 48 | 114 | 118.5 | | | | Excluded | D | Lind *et al.* Manuscript |
| Pimephales promelas | fathead minnow | 45 | 121 | 133.6 | | | | Excluded | D | Lind *et al.* Manuscript |
| Pimephales promelas | fathead minnow | 46 | 88.5 | 95.7 | | | | Excluded | D | Lind *et al.* Manuscript |

# Table IX.8-1
## Copper Toxicity Database (Continued)

| Species | Common name | Hardness | LC50 | | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Reported | Adjusted to Hardness of 50 mg/L | | | | | | |
| Pimephales promelas (adult) | fathead minnow | 103 | 210 | 106.3 | | | | Excluded | D | Birge *et al.* 1983 |
| Pimephales promelas (adult) | fathead minnow | 103 | 310 | 156.9 | | | | Excluded | D | Birge *et al.* 1983 |
| Pimephales promelas (adult) | fathead minnow | 103 | 120 | 60.7 | | | | Excluded | D | Birge *et al.* 1983 |
| Pimephales promelas (adult) | fathead minnow | 163 | 390 | 128.1 | 117.6 | | | Excluded | D | Birge *et al.* 1983 |
| Ptychochielus oregonensis | northern squawfish | 54 | 18 | 16.7 | 16.7 | | | Excluded | D | Andros & Garton 1980 |
| Rhinichthys atratulus | blacknose dace | 200 | 320 | 86.7 | 86.7 | | | Excluded | D | Geckler *et al.* 1976 |
| Semotilus atromaculatus | creek chub | 200 | 310 | 84.0 | 84.0 | | | Included | A | Geckler *et al.* 1976 |
| Ictalurus nebulosus | brown bullhead | 202 | 170 | 45.6 | | | | Excluded | D | Brungs *et al.* 1973 |
| Ictalurus nebulosus | brown bullhead | 202 | 190 | 51.0 | | | | Excluded | D | Brungs *et al.* 1973 |
| Ictalurus nebulosus | brown bullhead | 200 | 540 | 146.3 | 69.8 | | | Excluded | D | Geckler *et al.* 1976 |
| Fundulus diaphanus | banded killfish | 53 | 860 | 814.1 | | | | Excluded | D | Rehwoldt *et al.* 1971 |
| Fundulus diaphanus | banded killfish | 55 | 840 | 767.9 | 790.6 | | | Excluded | D | Rehwoldt *et al.* 1972 |
| Gambusia affinis (female) | mosquitofish | 34 | 93 | 133.7 | | | | Excluded | D | Joshi & Rege 1980 |
| Gambusia affinis (female) | mosquitofish | 34 | 200 | 287.6 | 196.1 | | | Excluded | D | Joshi & Rege 1980 |
| Poecilia reticulata | guppy | 20 | 36 | 85.4 | | | | Excluded | D | Chynoweth *et al.* 1976 |
| Poecilia reticulata | guppy | 87.5 | 112 | 66.1 | | | | Excluded | D | Black 1974; Chynoweth et al . 1976 |
| Poecilia reticulata | guppy | 67.2 | 138 | 104.4 | | | | Excluded | D | Black 1974; Chynoweth et al . 1976 |
| Poecilia reticulata (6.5 mg) | guppy | 166 | 160 | 51.7 | | | | Excluded | D | Deshmukh & Marathe 1980 |

# Table IX.8-1
# Copper Toxicity Database (Continued)

| Species | Common name | Hardness | LC50 | | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Reported | Adjusted to Hardness of 50 mg/L | | | | | | |
| Poecilia reticulata (63 mg; female) | guppy | 166 | 275 | 88.8 | | | | Excluded | D | Deshmukh & Marathe 1980 |
| Poecilia reticulata 60 mg; male) | guppy | 166 | 210 | 67.8 | | | | Excluded | D | Deshmukh & Marathe 1980 |
| Poecilia reticulata (340 mg; female) | guppy | 166 | 480 | 155.0 | | | | Excluded | D | Deshmukh & Marathe 1980 |
| Poecilia reticulata | guppy | 230 | 1230 | 292.0 | | | | Excluded | D | Khangarot 1981 |
| Poecilia reticulata | guppy | 240 | 764 | 174.3 | 104.2 | | | Excluded | D | Khangarot *et al.* 1981b |
| Macquaria ambigua | golden perch | 50 | 158.1 | 158.1 | 158.1 | | | Excluded | D | Skidmore and Firth 1983 |
| Morone americana | white perch | 55 | 6200 | 5667.5 | | | | Excluded | D | Rehwoldt *et al.* 1971 |
| Morone americana | white perch | 55 | 6400 | 5850.3 | 5758.2 | | | Excluded | D | Rehwoldt *et al.* 1971 |
| Morone saxatilis | striped bass | 53 | 4300 | 4070.3 | | | | Excluded | D | Rehwoldt *et al.* 1971 |
| Morone saxatilis | striped bass | 55 | 4000 | 3656.5 | | | | Excluded | D | Rehwoldt *et al.* 1972 |
| Morone saxatilis | striped bass | 35 | 620 | 867.6 | | | | Excluded | D | Welborn 1969 |
| Morone saxatilis (larva) | striped bass | 34.5 | 50 | 70.9 | | | | Excluded | D | Hughes 1973 |
| Morone saxatilis (fingerling) | striped bass | 34.5 | 50 | 70.9 | | | | Excluded | D | Hughes 1973 |
| Morone saxatilis (larva) | striped bass | 34.5 | 25 | 35.5 | | | | Excluded | D | Hughes 1973 |
| Morone saxatilis (fingerling) | striped bass | 34.5 | 38 | 53.9 | 55.7 | | | Excluded | D | Hughes 1973 |
| Lepomis gibbosus | pumpkinseed | 53 | 2400 | 2271.8 | | | | Excluded | D | Rehwoldt *et al.* 1971 |
| Lepomis gibbosus | pumpkinseed | 55 | 2700 | 2468.1 | | | | Excluded | D | Rehwoldt *et al.* 1972 |
| Lepomis gibbosus | pumpkinseed | 125 | 1240 | 523.0 | | | | Excluded | D | Spear 1977; Anderson & Spear 1980b |
| Lepomis gibbosus | pumpkinseed | 125 | 1300 | 548.3 | | | | Excluded | D | Spear 1977; Anderson & Spear 1980b |
| Lepomis gibbosus | pumpkinseed | 125 | 1670 | 704.3 | | | | Excluded | D | Spear 1977; Anderson & Spear |

## Table IX.8-1
## Copper Toxicity Database (Continued)

| Species | Common name | Hardness | LC50 | | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Reported | Adjusted to Hardness of 50 mg/L | | | | | | |
| | | | | | | | | | | 1980b |
| Lepomis gibbosus | pumpkinseed | 125 | 1940 | 818.2 | | | | Excluded | D | Spear 1977; Anderson & Spear 1980b |
| Lepomis gibbosus | pumpkinseed | 125 | 1240 | 523.0 | | | | Excluded | D | Spear 1977; Anderson & Spear 1980b |
| Lepomis gibbosus | pumpkinseed | 125 | 1660 | 700.1 | | | | Excluded | D | Spear 1977; Anderson & Spear 1980b |
| Lepomis gibbosus | pumpkinseed | 125 | 1740 | 733.9 | 856.8 | | | Excluded | D | Spear 1977; Anderson & Spear 1980b |
| Lepomis macrochirus | bluegill | 52 | 400 | 385.5 | | | | Excluded | D | Inglis & Davis 1972 |
| Lepomis macrochirus | bluegill | 209 | 680 | 176.7 | | | | Excluded | D | Inglis & Davis 1972 |
| Lepomis macrochirus | bluegill | 365 | 1020 | 156.7 | | | | Excluded | D | Inglis & Davis 1972 |
| Lepomis macrochirus | bluegill | 45 | 1100 | 1214.8 | | | | Excluded | D | Benoit 1975 |
| Lepomis macrochirus | bluegill | 200 | 8300 | 2248.1 | | | | Excluded | D | Geckler *et al.* 1976 |
| Lepomis macrochirus | bluegill | 200 | 10000 | 2708.6 | | | | Excluded | D | Geckler *et al.* 1976 |
| Lepomis macrochirus | bluegill | 20 | 200 | 474.2 | | | | Excluded | D | Tarzwell & Hendersen 1960 |
| Lepomis macrochirus | bluegill | 400 | 10000 | 1409.6 | | | | Excluded | D | Tarzwell & Hendersen 1960 |
| Lepomis macrochirus | bluegill | 43 | 770 | 887.6 | | | | Excluded | D | Academy of Natural Sciences 1960 |
| Lepomis macrochirus | bluegill | 43 | 1250 | 1440.9 | | | | Excluded | D | Academy of Natural Sciences 1960; Patrick *et al.* 1968; Cairns & Scheier 1968 |
| Lepomis macrochirus | bluegill | 20 | 660 | 1564.9 | | | | Excluded | D | Pickering & Henderson 1966 |
| Lepomis macrochirus | bluegill | 360 | 10200 | 1587.9 | | | | Excluded | D | Pickering & Henderson 1966 |
| Lepomis macrochirus | bluegill | 35 | 2400 | 3358.6 | | | | Excluded | D | O'Hara 1971 |
| Lepomis macrochirus | bluegill | 40 | 1000 | 1234.0 | | | | Excluded | D | Thompson *et al.* 1980 |
| Lepomis macrochirus | bluegill | 26 | 1000 | 1851.7 | 1017.0 | | | Excluded | D | Cairns *et al.* 1980 |

# Table IX.8-1
# Copper Toxicity Database (Continued)

| Species | Common name | Hardness | LC50 | | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Reported | Adjusted to Hardness of 50 mg/L | | | | | | |
| Galaxias maculatus | jollytail | 50 | 70.7 | 70.7 | 70.7 | | | Excluded | D | Skidmore and Firth 1983 |
| Etheostoma caeruleum | rainbow darter | 200 | 320 | 86.7 | 86.7 | | | Excluded | D | Geckler *et al.* 1976 |
| Etheostoma spectabile | orangethroat darter | 200 | 850 | 230.2 | 230.2 | | | Excluded | D | Geckler *et al.* 1976 |
| Mozambique mossambica | Mozambique tilapia | 115 | 1500 | 684.3 | 684.3 | | | Excluded | D | Qureshi & Saksena 1980 |

[1]Reasons for inclusion or exclusion:

**A** - Toxicity data on species that are known to occur or may occur at the site can not be excluded.

**B** - If a member of a family of freshwater fish may occur at the site, then toxicity data from any fish species within that family is maintained in the database.

**C** - If a member of a class of freshwater invertebrates may occur at the site, then all toxicity data from that invertebrate class is retained in the toxicity database.

**D** - Toxicity data on species that are not known to occur or are not likely to occur at the site are excluded.

**E** - Data was excluded for acute toxicity measurements if measured chronic values were available for the species.

Species mean acute values were calculated for each species within the acute toxicity database. The acute values were hardness adjusted to 50 mg/L when hardness adjustment was applicable (*e.g.*, Table IX.8-1). An appropriate ACR was applied to the species mean acute value to generate a predicted species mean chronic value. As indicated earlier, if measured chronic toxicity data were available for a given species, the measured value replaced the predicted chronic value in the database.

Species mean chronic values were than ranked from lowest concentration to highest concentration and the cumulative probability was determined (*e.g.*, Table IX.8-2). The cumulative probability represents the percentage of species within a community that would be affected by a specified concentration.

The third step in the statistical analysis process utilizes the species mean chronic values and the percent affected data to generate a SSD. These data sets were first assessed for a linear relationship defined by a simple linear regression model. If the data did not meet the requirements of a linear model, a non-linear regression (*i.e.*, logistic regression) was completed.

Logistic regression models were fit to the chronic SSDs (*e.g.*, Figure IX.8-1). The result was a sigmoid curve fit to the data that provided a model to calculate community effects from specified concentrations. Because of the sigmoidal shape of the curve, the fit of the model decreases at the tails of the distribution, resulting in a more conservative number than would be generated by fitting to the available data. This was not considered a problem because it is more conservative and thus provides some control over the uncertainty associated with the estimated chronic toxicity values.

#### 1.2.1.3 Interpretation of Output

The output from the SSDs illustrates the protection of the ecosystem at the community level. The proportions along the Y-axis represent the fraction of species in a community potentially at risk from a particular concentration. The units of the Y-axis can be defined as the potentially affected fractions (PAF) or percent affected.

Following the development of an appropriate regression model, hazard concentrations related to 5, 10, and 20% effect levels were determined as site-specific water quality benchmarks (*e.g.*, Figure IX.8-1). The selected hazard concentration percentages ($HC_p$) were chosen based on the following rational:

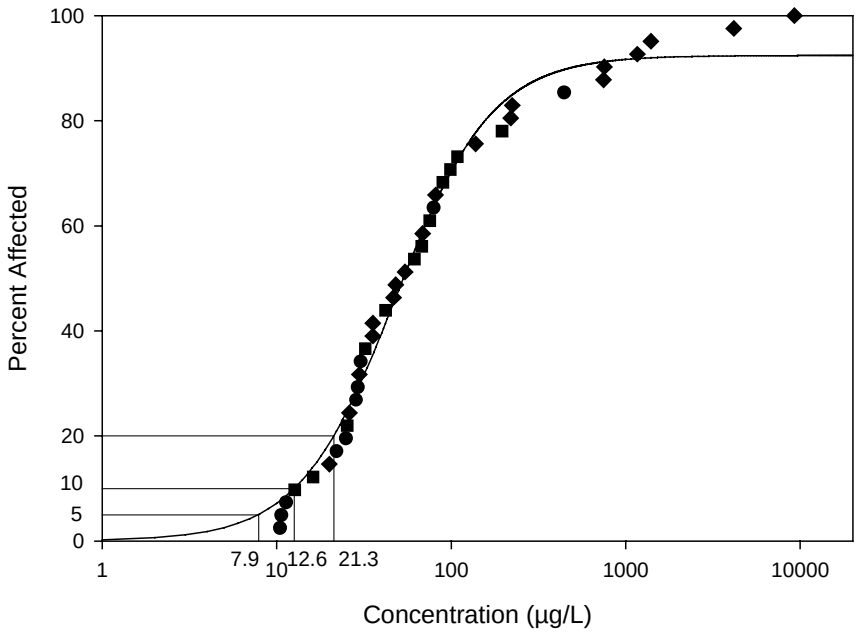
## Table IX.8-2
## Copper Toxicity Data for the Development of the Species Sensitivity Distributions

| Species | Common Name | Selected Chronic Value at 180 mg/L Hardness[1] | Percent Community Affected |
|---|---|---|---|
| Ceriodaphnia dubia | cladoceran | 10.47 | 2.44 |
| Daphnia pulicaria | cladoceran | 10.64 | 4.88 |
| Ceriodaphnia reticulata | cladoceran | 11.35 | 7.32 |
| Oncorhyncus kisutch (smolt) | coho salmon | 12.68 | 9.76 |
| Oncorhynchus tshawtscha | chinook salmon | 16.19 | 12.20 |
| Gammarus pseudolimnaeus | amphipod | *20.03* | 14.63 |
| Moina dubia | cladoceran | 22.06 | 17.07 |
| Daphnia magna | cladoceran | ***24.98***[a] | 19.51 |
| Salmo clarki | cutthroat trout | 25.38 | 21.95 |
| Gammarus pulex | amphipod | 26.07 | 24.39 |
| Daphnia ambigua | cladoceran | 28.50 | 26.83 |
| Daphnia pulex | cladoceran | 29.22 | 29.27 |
| Physa heterostropha | snail | 29.80 | 31.71 |
| Daphnia parvula | cladoceran | 30.34 | 34.15 |
| Semotilus atromaculatus | creek chub | 32.18 | 36.59 |
| Campeloma decisum | snail | *35.56* | 39.02 |
| Physa integra | snail | *35.56* | 41.46 |
| Salvelinus fontinalis | brook trout | *42.13* | 43.90 |
| Gyraulus circumstriatus | snail | 46.65 | 46.34 |
| Limnodrilus hoffmeisteri | worm | 48.06 | 48.78 |
| Clisttornia magnifica | caddisfly | *54.38* | 51.22 |
| Oncorhynchus mykiss | rainbow trout | *61.55* | 53.66 |
| Catostomus commersoni | white sucker | *67.82* | 56.10 |
| Echinogammarus berilloni | amphipod | 68.54 | 58.54 |
| Salmo salar | atlantic salmon | 75.31 | 60.98 |
| Daphnia rosea | cladoceran | 79.29 | 63.41 |
| Nais sp. | worm | 81.49 | 65.85 |
| Oncorhynchus nerka (fingerling) | sockeye salmon | 89.55 | 68.29 |
| Salvelinus namaycush | lake trout | *98.90* | 70.73 |
| Salmo trutta | brown trout | *108.46* | 73.17 |
| Goniobasis livenscens | snail | 137.94 | 75.61 |
| Esox lucius | northern pike | *195.70* | 78.05 |
| Lumbriculus variegatus | worm | 219.77 | 80.49 |
| Chironomus riparius | midge | 223.73 | 82.93 |
| Alona Afinis | cladoceran | 443.93 | 85.37 |
| Amnicola sp.(adult) | snail | 746.97 | 87.80 |
| Chironomus decorus | midge | 754.75 | 90.24 |
| Crangonyx pseudogracilis | amphipod | 1167.98 | 92.68 |
| Chironomus tentans | midge | 1394.75 | 95.12 |
| Unidentified | damselfly | 4164.90 | 97.56 |
| Acroneuria lycorias | stonefly | 9273.24 | 100.00 |

[1]Values in italics represent measured chronic values. All other values in this column represent predicted species mean chronic values.

[a]Bolded value is the geometric mean of three measured chronic values (*i.e.,* 2.8 µg/g, 13.40 µg/g, and 15.69 µg/L) for this species.

**Figure IX.8-1 Species Sensitivity Distribution for Copper. Based on Measured and Predicted Chronic Concentrations (● = cladocerans, ■ = fish, and ♦ = other invertebrates). Calculated at a hardness of 180 mg/L.**




$HC_5$ – equivalent to the U.S. EPA final chronic value calculation process for protection of aquatic life. This hazard concentration assumes that protecting 95% of the community from potential chronic effects will not cause unacceptable harm to the aquatic community as a whole (Suter and Barnthouse 1993).

$HC_{10}$ – consistent with the ARAMDG as a threshold value. This hazard concentration assumes that protection of 90% of the species in a community will maintain structure and function (*i.e.*, if the 90$^{th}$ percentile of the expected environmental concentrations exceeds the 10$^{th}$ percentile of the SSD then impacts may occur (Posthuma *et al.* 2002).

$HC_{20}$ – consistent with Oregon Department of Environmental Quality (ODEQ) assessment of minimum risk provided that the probability of exceeding the $HC_{20}$ is less than 10% (ODEQ 1998). This hazard concentration assumes protections of 80% of the aquatic community from chronic exposure. It is an operational hazard concentration used for the Snap Lake Diamond Project EA to define a point that if exceeded will have an influence on the aquatic community. This hazard concentration is based upon Suter *et al.* (1995), and represents a suggested *de minimus* level of risk for populations.

Comparisons of the $HC_5$ with effects observed in multi species tests or experiments have been completed (Emams *et al.* 1993). In general, the $HC_5$ appeared to be lower than the mean model ecosystem effect concentrations and is thus protective of the ecosystems. However, these results are very site-specific and may not be easily replicated in a different model ecosystem.

The site-specific benchmarks are then compared to expected environmental concentrations at the source and within the receiving waterbody to provide an assessment on the magnitude of a potential impact.

### 1.3 Site-Specific Water Quality Benchmarks

Site-specific benchmarks were developed for parameters that exceeded CCME guidelines or U.S. EPA criteria (if no CCME guideline was available), within greater than 1% of the receiving waterbody. For the Snap Lake Diamond Project, site-specific water quality benchmarks were developed for copper (Cu), cadmium (Cd), and chromium (hexavalent and trivalent forms).

#### 1.3.1 Copper

The toxicity database generated for Cu is provided in Table IX.8-1 and consists of all toxicity information meeting either the CCME or U.S. EPA toxicity data requirements for acceptance, as well as species mean acute values, measured chronic values and calculated ACR. As indicated in the methodology above, not all species were considered to be appropriate for inclusion in the development of site-specific benchmarks for the Snap Lake Diamond Project. Toxicity data included and excluded from the database is indicated in Table IX.8-1, along with reasons for inclusion or exclusion. The toxicity data in Table IX.8-1 is based on adjustments to a standard hardness of 50 milligrams per Litre (mg/L), using the standard hardness correction formula:

$$\left(\frac{50}{test\,hardness}\right)^{slope} * measured\,value$$

where slope was based on the U.S. EPA (1985a) acute and chronic slope values of 0.9422 and 0.8545, respectively. Adjustment to a standardized hardness of 50 mg/L in Table IX.8-1 was completed to provide consistency with reported literature and U.S. EPA database values.

The toxicity data provided in Table IX.8-1 was summarized to generate single chronic values for all included species. The selected chronic values were either predicted from acute values using appropriate ACR values or were actual measured chronic values.

It is well known that water hardness is an important factor in modifying the toxicity of Cu to aquatic biota. Therefore all data was standardized to a hardness of 180 mg/L (Table IX.8-2) by using the standard hardness correction formula and the chronic slope

$$\left(\frac{180}{50}\right)^{slope} * chronic\ value\ at\ 50\ mg/L$$

value for Cu of 0.8545. This was deemed an appropriate hardness value, because the hardness of Snap Lake is expected to exceed 200 mg/L during operations of the mine.

Species sensitivity distributions were generated from the data provided in Table IX.8-2, which includes species names, selected chronic values and estimates of the percent community affected.

The SSD for Cu is provided in Figure IX.8-1. The concentration data are plotted on a lognormal scale with the cumulative probability expressed as a percentage.

As illustrated in Figure IX.8-1, the most sensitive species are cladocerans followed by other invertebrates and fish. However, there is a broad range of all three of these groups throughout the SSD.

A logistic regression was fit to the Cu data and is illustrated as a line on Figure IX.8-1. The results of the non-linear regression analysis indicated a good fit with an $r^2 = 0.97$. The resulting logisitic regression model was:

$$y = \frac{92.4215}{1+\left(\frac{x}{47.9775}\right)^{-1.5778}}$$

where y = percent of aquatic community affected; and x = concentration at a hardness of 180 mg/L.

Based on the above equation, appropriate hazard concentrations were generated for 5, 10, and 20% effect levels, at concentrations of 7.9, 12.6 and 21.3 micrograms per litre (µg/L), respectively. These concentrations are provided on Figure IX.8-1 and are based on a hardness concentration of 180 mg/L. Note that because of the conservative nature of the logisitic regression at the lower tail, the $HC_5$ concentration is lower than the measured lowest chronic effect concentrations.

Hazard concentrations may be calculated at different hardness values using the standard hardness correction formula.

### 1.3.2 Cadmium

The toxicity database generated for Cd is provided in Table IX.8-3 and consists of all toxicity information meeting either the CCME or U.S. EPA toxicity data requirements for acceptance, as well as species mean acute values, measured chronic values and calculated ACR. As indicated in the methodology above, not all species were considered to be appropriate for inclusion in the development of site-specific benchmarks for the Snap Lake Diamond Project. Toxicity data included or excluded from the database is indicated in Table IX.8-3, along with an appropriate explanation. All data in this table were adjusted to a hardness of 50 mg/L using the same formula as presented in Section 1.3.1 and a slope value of 1.0166 and 0.7409 for acute and chronic data, respectively.

Measured chronic toxicity values are more readily available for Cd relative to other metals. In cases where there were actual measured chronic values for a species, this value was used instead of the predicted value from a species mean acute value and an ACR. If multiple measured chronic values were available for a species, the geometric means of the measured values were used in the SSD (*e.g.*, *Daphnia magna*).

Species sensitivity distributions were generated from the data provided in Table IX.8-4. This includes species identification, selected chronic values (predicted or measured) and the cumulative probability (*i.e.*, percent community affected) data. It is well known that water hardness is an important factor in modifying the toxicity of Cd to aquatic biota. Therefore all chronic toxicity data was standardized to a common hardness of 180 mg/L using the pooled slope (0.7409) value provided by the U.S. EPA (2001) and the standard hardness correction formula listed above (Section 1.3.1).

The SSD for Cd is provided in Figure IX.8-2. The concentration data were plotted on a lognormal scale with the cumulative probability expressed as a percentage.

# Table IX.8-3
# Cadmium Toxicity Database

| Species | Common Name | $LC_{50}$ or $EC_{50}$ Adjusted to 50 mg/L Hardness | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L Hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | References |
|---|---|---|---|---|---|---|---|---|
| Dendrocoelum lacteum | Planarian | 14067 | 14067 | | | Included | A | Ham *et al.* 1995 |
| Lumbriculus variegatus | Worm (Adult) | 130.6 | 130.6 | | | Included | A | Schubauer- Berigan *et al.* 1993 |
| Branchiura sowerbyi | Tubificid worm | 2350 | 2350 | | | Included | A | Chapman *et al.* 1982 |
| Limnodrilus hoffmeisteri | Tubificid worm | 1665 | | | | Included | A | Chapman *et al.* 1982 |
| Limnodrilus hoffmeisteri | Tubificid worm | 775 | 775 | | | Included | A | Williams *et al.* 1985 |
| Quistadrilus multisetosus | Tubificid worm | 3133 | 3133 | | | Included | A | Chapman *et al.* 1982 |
| Rhyacodrilus montana | Tubificid worm | 6169 | 6169 | | | Included | A | Chapman *et al.* 1982 |
| Spirosperma ferox | Tubificid worm | 3427 | 3427 | | | Included | A | Chapman *et al.* 1982 |
| Spirosperma nikolskyi | Tubificid worm | 4406 | 4406 | | | Included | A | Chapman *et al.* 1982 |
| Stylodrilus heringlianus | Tubificid worm | 5386 | 5386 | | | Included | A | Chapman *et al.* 1982 |
| Tubifex tubifex | Tubificid worm | 1231 | | | | Included | A | Reynoldson *et al.* 1996 |
| Tubifex tubifex | Tubificid worm | 653.8 | | | | Included | A | Reynoldson *et al.* 1996 |
| Tubifex tubifex | Tubificid worm | 3133 | 1361 | | | Included | A | Chapman *et al.* 1982 |
| Varichaeta pacifica | Tubificid worm | 3721 | 3721 | | | Included | A | Chapman *et al.* 1982 |
| Aeolosoma headleyi | worm | | | 20.74 | | Included | A | Niederlehner 1984 |
| Gossiponia complanta | Leech | 192.5 | 192.5 | | | Included | C | Brown and Pascoe 1988 |
| Aplexa hypnorum | Snail | 102.8 | | 3.723 | 26.88 | Included | A | Holcombe *et al.*, 1984 |
| Aplexa hypnorum | Snail | 104.9 | 103.9 | 6.241 | 16.03 | Included | A | Phipps and Holcombe 1985 |
| Physa gyrina | Snail | 334.7 | | | | Included | A | Wier and Walter 1976 |
| Physa gyrina | Snail | 100.2 | 100.2 | | | Included | A | Wier and Walter 1976 |
| Actinonaia pectorosa | Mussel | 28.06 | | | | Excluded | D | Keller Unpublished |
| Actinonaia pectorosa | Mussel | 40.72 | 33.8 | | | Excluded | D | Keller Unpublished |
| Lampsilis straminea claibornenis | Mussel | 47.68 | 47.68 | | | Excluded | D | Keller Unpublished |
| Lampsilis teres | Mussel | 13.8 | | | | Excluded | D | Keller Unpublished |

# Table IX.8-3
## Cadmium Toxicity Database (Continued)

| Species | Common Name | $LC_{50}$ or $EC_{50}$ Adjusted to 50 mg/L Hardness | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L Hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | References |
|---|---|---|---|---|---|---|---|---|
| Lampsilis teres | Mussel | 41.4 | 23.9 | | | Excluded | D | Keller Unpublished |
| Utterbackia imbecilis | Mussel | 63.1 | | | | Excluded | D | Keller Unpublished |
| Utterbackia imbecilis | Mussel | 61.51 | | | | Excluded | D | Keller Unpublished |
| Utterbackia imbecilis | Mussel | 44.06 | | | | Excluded | D | Keller Unpublished |
| Utterbackia imbecilis | Mussel | 53.59 | | | | Excluded | D | Keller Unpublished |
| Utterbackia imbecilis | Mussel | 11.59 | | | | Excluded | D | Keller and Zam 1991 |
| Utterbackia imbecilis | Mussel | 58.87 | 42.92 | | | Excluded | D | Keller and Zam 1991 |
| Vilosa vibex | Mussel | 37.64 | | | | Excluded | D | Keller Unpublished |
| Vilosa vibex | Mussel | 32.88 | 35.18 | | | Excluded | D | Keller Unpublished |
| Alona affinis | Cladoceran | 247.2 | 247.2 | | | Included | C | Ghosh *et al.* 1990 |
| Ceriodaphnia dubia | Cladoceran | 29.71 | | | | Excluded | C | Bitton *et al.* 1996 |
| Ceriodaphnia dubia | Cladoceran | 33.8 | | | | Excluded | C | Diamond *et al.* 1997 |
| Ceriodaphnia dubia | Cladoceran | 30.75 | 31.37 | | | Excluded | C | Lee *et al.* 1997 |
| Ceriodaphnia dubia | Cladoceran | na | | 27.17 | | Included | C | Jop et al 1995 |
| Ceriodaphnia reticulata | Cladoceran | 37.35 | | | | Included | C | Elnabarawy *et al.* 1986 |
| Ceriodaphnia reticulata | Cladoceran | 45.17 | 41.07 | | | Included | C | Hall *et al.* 1986 |
| Daphnia magna | Cladoceran | 72.35 | | | | Excluded | C | Biesinger and Christensen, 1972 |
| Daphnia magna | Cladoceran | 14.11 | | | | Excluded | E | Canton and Slooff 1982 |
| Daphnia magna | Cladoceran | 7.002 | | | | Excluded | E | Canton and Slooff 1982 |
| Daphnia magna | Cladoceran | 8.213 | | | | Excluded | E | Hall *et al.* 1986 |
| Daphnia magna | Cladoceran | 16.43 | | | | Excluded | E | Hall *et al.* 1986 |
| Daphnia magna | Cladoceran | 36.13 | | | | Excluded | E | Elnabarawy *et al.* 1986 |
| Daphnia magna | Cladoceran | 1.038 | | | | Excluded | E | Baird *et al.* 1991 |
| Daphnia magna | Cladoceran | 2.594 | | | | Excluded | E | Baird *et al.* 1991 |
| Daphnia magna | Cladoceran | 2.594 | | | | Excluded | E | Baird *et al.* 1991 |
| Daphnia magna | Cladoceran | 1.297 | | | | Excluded | E | Baird *et al.* 1991 |

## Table IX.8-3
## Cadmium Toxicity Database (Continued)

| Species | Common Name | $LC_{50}$ or $EC_{50}$ Adjusted to 50 mg/L Hardness | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L Hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | References |
|---|---|---|---|---|---|---|---|---|
| Daphnia magna | Cladoceran | 7.81 | | | | Excluded | E | Baird *et al.* 1991 |
| Daphnia magna | Cladoceran | 33.4 | | | | Excluded | E | Baird *et al.* 1991 |
| Daphnia magna | Cladoceran | 7.061 | | | | Excluded | E | Stuhlbacher *et al.* 1992 |
| Daphnia magna | Cladoceran | 37.29 | | | | Excluded | E | Stuhlbacher *et al.* 1992 |
| Daphnia magna | Cladoceran | 7.32 | | | | Excluded | E | Stuhlbacher *et al.* 1992 |
| Daphnia magna | Cladoceran | 65.94 | | | | Excluded | E | Stuhlbacher *et al.* 1992 |
| Daphnia magna | Cladoceran | 14.15 | | | | Excluded | E | Stuhlbacher *et al.* 1992 |
| Daphnia magna | Cladoceran | 72.08 | | | | Excluded | E | Stuhlbacher *et al.* 1992 |
| Daphnia magna | Cladoceran | 37.81 | | | | Excluded | E | Stuhlbacher *et al.* 1992 |
| Daphnia magna | Cladoceran | 92.02 | | | | Excluded | E | Stuhlbacher *et al.* 1992 |
| Daphnia magna | Cladoceran | 40.32 | | | | Excluded | E | Stuhlbacher *et al.* 1992 |
| Daphnia magna | Cladoceran | 94.04 | | | | Excluded | E | Stuhlbacher *et al.* 1992 |
| Daphnia magna | Cladoceran | 42.28 | | | | Excluded | E | Stuhlbacher *et al.* 1992 |
| Daphnia magna | Cladoceran | 102.4 | | | | Excluded | E | Stuhlbacher *et al.* 1992 |
| Daphnia magna | Cladoceran | 54.52 | | | | Excluded | E | Crisinel *et al.* 1994 |
| Daphnia magna | Cladoceran | 2.738 | | | | Excluded | E | Guilhermino *et al.* 1996 |
| Daphnia magna | Cladoceran | 121.6 | | | | Excluded | E | Barata *et al.* 1998 |
| Daphnia magna | Cladoceran | 57.86 | | | | Excluded | E | Barata *et al.* 1998 |
| Daphnia magna | Cladoceran | 63.72 | | | | Excluded | E | Barata *et al.* 1998 |
| Daphnia magna | Cladoceran | 32.69 | | | | Excluded | E | Barata *et al.* 1998 |
| Daphnia magna | Cladoceran | 12.77 | | | | Excluded | E | Barata *et al.* 1998 |
| Daphnia magna | Cladoceran | 6.454 | | | | Excluded | E | Barata *et al.* 1998 |
| Daphnia magna | Cladoceran | 9.703 | | 0.1459 | | Included | A | Chapman *et al.* Manuscript |
| Daphnia magna | Cladoceran | 15.67 | | 0.1239 | | Included | A | Chapman *et al.* Manuscript |
| Daphnia magna | Cladoceran | 15.99 | | | | Excluded | E | Chapman *et al.* Manuscript |

## Table IX.8-3
## Cadmium Toxicity Database (Continued)

| Species | Common Name | $LC_{50}$ or $EC_{50}$ Adjusted to 50 mg/L Hardness | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L Hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | References |
|---|---|---|---|---|---|---|---|---|
| Daphnia magna | Cladoceran | 15.63 | | 0.1515 | 104.3 | Included | A | Chapman *et al.* Manuscript |
| Daphnia magna | Cladoceran | 11.45 | | | | Excluded | E | Chapman *et al.* Manuscript |
| Daphnia magna | Cladoceran | n/a | | 3.133 | | Included | A | Bodar et al 1988 b |
| Daphnia magna | Cladoceran | 21.96 | 13.41 | | | Excluded | E | Attar and Maly 1982 |
| Daphnia pulex | Cladoceran | 41.14 | | | | Excluded | E | Bertram and Hart 1979 |
| Daphnia pulex | Cladoceran | 64.75 | | | | Excluded | E | Elnabarawy *et al.* 1986 |
| Daphnia pulex | Cladoceran | 32.85 | | | | Excluded | E | Hall *et al.* 1986 |
| Daphnia pulex | Cladoceran | 41.07 | | | | Excluded | E | Hall *et al.* 1986 |
| Daphnia pulex | Cladoceran | 65.44 | | | | Excluded | E | Stackhouse and Benson, 1988 |
| Daphnia pulex | Cladoceran | 38.48 | | | | Excluded | E | Roux *et al.* 1993 |
| Daphnia pulex | Cladoceran | 57.72 | | | | Excluded | E | Roux *et al.* 1993 |
| Daphnia pulex | Cladoceran | 40.82 | 46.36 | | | Excluded | E | Roux *et al.* 1993 |
| Daphnia pulex | Cladoceran | n/a | | 6.167 | | Included | C | Niederlehner 1984 |
| Unknown | Cladoceran | 43.09 | 43.09 | | | Excluded | G | Hatakeyama and Yasuno |
| Simocephalus serrulatus | Cladoceran | 32.33 | | | | Included | C | Giesy *et al.* 1977 |
| Simocephalus serrulatus | Cladoceran | 28.23 | 30.21 | | | Included | C | Spehar and Carlson, 1984 a,b |
| Cyclops varicans | Copepod | 223.2 | 223.2 | | | Included | C | Ghosh *et al.* 1990 |
| Asellus bicrenata | Isopod | 472.1 | 472.1 | | | Included | C | Bosnak and Morgan 1981 |
| Lirceus alabamae | Isopod | 48.44 | 48.44 | | | Included | C | Bosnak and Morgan 1981 |
| Crangonyx pseudogracilis | Amphipod | 1700 | 1700 | | | Included | C | Martin and Holdich 1986 |
| Gammarus pseudolimnaeus | Amphipod | 78.69 | 7869 | | | Included | A | Spehar and Carlson 1984a, b |

## Table IX.8-3
## Cadmium Toxicity Database (Continued)

| Species | Common Name | $LC_{50}$ or $EC_{50}$ Adjusted to 50 mg/L Hardness | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L Hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | References |
|---|---|---|---|---|---|---|---|---|
| Hyalella azteca | Amphipod | n/a | | 0.2747 | | Included | A | Ingersoll and Kemble unpublished |
| Orconectes immunis | Crayfish | 11509 | 11509 | | | Excluded | D | Phipps and Holcombe 1985 |
| Orconectes virilis | Crayfish | 11859 | 11859 | | | Excluded | D | Mirenda 1986 |
| Procambarus clarkii | Crayfish | 1748 | 1748 | | | Excluded | D | Naqvi and Howell 1993 |
| Ephemerella grandis | Mayfly | 2278 | 2278 | | | Included | C | Warnick and Bell 1969 |
| Chironomus riparius | Midge | 55607 | | | | Included | C | Pascoe *et al.* 1990 |
| Chironomus riparius | Midge | 96880 | 96880 | | | Included | C | Williams *et al.* 1985 |
| Chironomus tentans | Midge | | | 2.804 | | Included | A | Ingersoll and Kemble unpublished |
| Pectinatella magnifica | Bryozoan | 166.8 | 166.8 | | | Excluded | D | Pardue and Wood 1980 |
| Lophopodella carteri | Bryozoan | 35.74 | 35.74 | | | Excluded | D | Pardue and Wood 1980 |
| Plumatella emarginata | Bryozoan | 259.7 | 259.7 | | | Excluded | D | Pardue and Wood 1980 |
| Oncorhynchus kisutch | Coho salmon | 5.722 | | | | Excluded | D | Lorz *et al.* 1978 |
| Oncorhynchus kisutch | Coho salmon | 4.16 | | | | Excluded | D | Buhl and Hamilton 1991 |
| Oncorhynchus kisutch | Coho salmon | 40.32 | | | | Excluded | D | Chapman 1975 |
| Oncorhynchus kisutch | Coho salmon | 6.221 | 6.221 | | | Excluded | D | Chapman 1975 |
| Oncorhynchus kisutch | Coho salmon | | | 2.311 | | Included | B | Eaton *et al.*, 1978 |
| Oncorhynchus kisutch | Coho salmon | | | 7.87 | | Included | B | Eaton *et al.*, 1978 |
| Oncorhynchus tshawytscha | Chinook salmon | 66.016 | | | | Excluded | E | Hamilton and Buhl 1990 |
| Oncorhynchus tshawytscha | Chinook salmon | 8.048 | | | | Excluded | E | Hamilton and Buhl 1990 |
| Oncorhynchus tshawytscha | Chinook salmon | 57.26 | | | | Excluded | E | Chapman 1975, 1978 |
| Oncorhynchus tshawytscha | Chinook salmon | 3.964 | | | | Excluded | E | Chapman 1975, 1978 |
| Oncorhynchus tshawytscha | Chinook salmon | 7.707 | | | | Excluded | E | Chapman 1975, 1978 |
| Oncorhynchus tshawytscha | Chinook salmon | 6.386 | | | | Excluded | E | Chapman 1975, 1978 |
| Oncorhynchus tshawytscha | Chinook salmon | 2.853 | | 2.612 | 1.09 | Included | B | Chapman 1982 |
| Oncorhynchus tshawytscha | Chinook salmon | 2.657 | 4.305 | | | Excluded | E | Finlayson and Verrue |

## Table IX.8-3
## Cadmium Toxicity Database (Continued)

| Species | Common Name | $LC_{50}$ or $EC_{50}$ Adjusted to 50 mg/L Hardness | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L Hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | References |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 1982 |
| Oncorhynchus mykiss | Rainbow trout | 2.65 | | | | Excluded | E | Spehar and Carlson, 1984 a, b |
| Oncorhynchus mykiss | Rainbow trout | 1.835 | | | | Excluded | E | Buhl and Hamilton 1991 |
| Oncorhynchus mykiss | Rainbow trout | 59.46 | | | | Excluded | E | Chapman 1975, 1978 |
| Oncorhynchus mykiss | Rainbow trout | 2.863 | | | | Excluded | E | Chapman 1975, 1978 |
| Oncorhynchus mykiss | Rainbow trout | 2.202 | | | | Excluded | E | Chapman 1975, 1978 |
| Oncorhynchus mykiss | Rainbow trout | 9.029 | | | | Excluded | E | Chapman 1975 |
| Oncorhynchus mykiss | Rainbow trout | 6.386 | | | | Excluded | E | Chapman 1975 |
| Oncorhynchus mykiss | Rainbow trout | 2.845 | | | | Excluded | E | Davies 1976 |
| Oncorhynchus mykiss | Rainbow trout | 3.385 | | | | Excluded | E | Phipps and Holcombe 1985 |
| Oncorhynchus mykiss | Rainbow trout | 2.795 | | | | Excluded | E | Cusimano *et al.* 1986 |
| Oncorhynchus mykiss | Rainbow trout | 1.166 | | | | Excluded | E | Stratus Consulting 1999 |
| Oncorhynchus mykiss | Rainbow trout | 0.8092 | | | | Excluded | E | Stratus Consulting 1999 |
| Oncorhynchus mykiss | Rainbow trout | 0.8105 | | | | Excluded | E | Stratus Consulting 1999 |
| Oncorhynchus mykiss | Rainbow trout | 0.6344 | | | | Excluded | E | Stratus Consulting 1999 |
| Oncorhynchus mykiss | Rainbow trout | 2.168 | | | | Excluded | E | Stratus Consulting 1999 |
| Oncorhynchus mykiss | Rainbow trout | 1.581 | 2.108 | | | Excluded | E | Stratus Consulting 1999 |
| Oncorhynchus mykiss | Rainbow trout | | | 1.308 | | Included | B | Stratus Consulting 1999 |
| Salmo trutta | Brown trout | 1.613 | 1.613 | | | Included | B | Spehar and Carlson, 1984a,b |
| Salmo trutta | Brown trout | | | 5.004 | | Included | B | Brown *et al.*, 1994 |
| Salmo trutta | Brown trout | | | 7.33 | | Included | B | Eaton *et al.*, 1978 |
| Salvelinus fontinalis | Brook trout | 5363 | | | | Excluded | E | Holcombe *et al.* 1983 |
| Salvelinus fontinalis | Brook trout | 1.792 | 1.792 | | | Excluded | E | Carroll *et al.* 1979 |
| Salvelinus fontinalis | Brook trout | | | 2.165 | | Included | B | Sauter *et al.*, 1976 |
| Salvelinus fontinalis | Brook trout | | | 2.248 | | Included | B | Eaton *et al.*, 1978 |

## Table IX.8-3
## Cadmium Toxicity Database (Continued)

| Species | Common Name | $LC_{50}$ or $EC_{50}$ Adjusted to 50 mg/L Hardness | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L Hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | References |
|---|---|---|---|---|---|---|---|---|
| Salvelinus fontinalis | Brook trout | | | 2.643 | | Included | B | Benoit *et al.*, 1976 |
| Salmo salar | Atlantic salmon | | | 7.922 | | Included | B | Rambough and Garside 1982 |
| Salvelinus confluentus | Bull trout | 1.494 | | | | Included | B | Stratus Consulting 1999 |
| Salvelinus confluentus | Bull trout | 1.705 | | | | Included | B | Stratus Consulting 1999 |
| Salvelinus confluentus | Bull trout | 1.589 | | | | Included | B | Stratus Consulting 1999 |
| Salvelinus confluentus | Bull trout | 1.503 | | | | Included | B | Stratus Consulting 1999 |
| Salvelinus confluentus | Bull trout | 4.858 | | | | Included | B | Stratus Consulting 1999 |
| Salvelinus confluentus | Bull trout | 3.361 | 2.152 | | | Included | B | Stratus Consulting 1999 |
| Salvelinus namaycush | Lake trout | | | 8.088 | | Included | A | Eaton *et al.*, 1978 |
| Esox lucius | Northern pike | | | 8.092 | | Included | A | Eaton *et al.*, 1978 |
| Carassius auratus | Goldfish | 5940 | | | | Excluded | D | Pickering and Henderson 1966 |
| Carassius auratus | Goldfish | 5407 | | | | Excluded | D | McCarty *et al.* 1978 |
| Carassius auratus | Goldfish | 16431 | | | | Excluded | D | McCarty *et al.* 1978 |
| Carassius auratus | Goldfish | 844 | 844 | | | Excluded | D | Phipps and Holcombe 1985 |
| Cyprinus carpio | Common carp | 2125 | | | | Excluded | D | Suresh *et al.* 1993a |
| Cyprinus carpio | Common carp | 8452 | 4238 | | | Excluded | D | Suresh *et al.* 1993a |
| Notropis lutrensis | Red shiner | 3837 | 3837 | | | Excluded | D | Carrier and Beitinger 1988a |
| Pimephales promelas | Fathead minnow | 2665 | | | | Excluded | D | Pickering and Henderson 1966 |
| Pimephales promelas | Fathead minnow | 1599 | | | | Excluded | D | Pickering and Henderson 1966 |
| Pimephales promelas | Fathead minnow | 9758 | | | | Excluded | D | Pickering and Henderson 1966 |
| Pimephales promelas | Fathead minnow | 9879 | | | | Excluded | D | Pickering and Henderson 1966 |

## Table IX.8-3
## Cadmium Toxicity Database (Continued)

| Species | Common Name | $LC_{50}$ or $EC_{50}$ Adjusted to 50 mg/L Hardness | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L Hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | References |
|---|---|---|---|---|---|---|---|---|
| Pimephales promelas | Fathead minnow | 2722 | | | | Excluded | D | Pickering and Gast 1972 |
| Pimephales promelas | Fathead minnow | 2917 | | | | Excluded | D | Pickering and Gast 1972 |
| Pimephales promelas | Fathead minnow | 1556 | | | | Excluded | D | Pickering and Gast 1972 |
| Pimephales promelas | Fathead minnow | 486.2 | | | | Excluded | D | Pickering and Gast 1972 |
| Pimephales promelas | Fathead minnow | 1094 | | | | Excluded | D | Pickering and Gast 1972 |
| Pimephales promelas | Fathead minnow | 26.97 | | | | Excluded | D | Spehar 1982 |
| Pimephales promelas | Fathead minnow | 12.2 | | | | Excluded | D | Spehar 1982 |
| Pimephales promelas | Fathead minnow | 24.85 | | | | Excluded | D | Spehar 1982 |
| Pimephales promelas | Fathead minnow | 47.19 | | | | Excluded | D | Spehar 1982 |
| Pimephales promelas | Fathead minnow | 57.72 | | | | Excluded | D | Spehar 1982 |
| Pimephales promelas | Fathead minnow | 33.02 | | | | Excluded | D | Spehar 1982 |
| Pimephales promelas | Fathead minnow | 1468 | | | | Excluded | D | Birge *et al.* 1983 |
| Pimephales promelas | Fathead minnow | 1391 | | | | Excluded | D | Birge *et al.* 1983 |
| Pimephales promelas | Fathead minnow | 1487 | | | | Excluded | D | Birge *et al.* 1983 |
| Pimephales promelas | Fathead minnow | 1327 | | | | Excluded | D | Birge *et al.* 1983 |
| Pimephales promelas | Fathead minnow | 1475 | | | | Excluded | D | Spehar and Carlson 1984 a,b |
| Pimephales promelas | Fathead minnow | 61.6 | | | | Excluded | D | Hall *et al.* 1986 |
| Pimephales promelas | Fathead minnow | 2075 | | | | Excluded | D | Carrier and Beitinger 1988a |
| Pimephales promelas | Fathead minnow | 174.5 | | | | Excluded | D | Rifici *et al.* 1996 |
| Pimephales promelas | Fathead minnow | 149.5 | | | | Excluded | D | Rifici *et al.* 1996 |
| Pimephales promelas | Fathead minnow | 12.22 | | | | Excluded | D | Schubauer-Berigan *et al.* 1993 |
| Pimephales promelas | Fathead minnow | 10.05 | | | | Excluded | D | Schubauer-Berigan *et al.* 1993 |
| Pimephales promelas | Fathead minnow | 10.88 | | | | Excluded | D | Schubauer-Berigan *et al.* 1993 |

## Table IX.8-3
## Cadmium Toxicity Database (Continued)

| Species | Common Name | $LC_{50}$ or $EC_{50}$ Adjusted to 50 mg/L Hardness | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L Hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | References |
|---|---|---|---|---|---|---|---|---|
| Pimephales promelas | Fathead minnow | 1192 | | | | Excluded | D | Sherman *et al.* 1987 |
| Pimephales promelas | Fathead minnow | 1223 | | | | Excluded | D | Sherman *et al.* 1987 |
| Pimephales promelas | Fathead minnow | 1693 | | | | Excluded | D | Phipps and Holcombe 1985 |
| Pimephales promelas | Fathead minnow | 15.03 | 29.21 | | | Excluded | D | Spehar and Fiandt 1986 |
| Ptychocheilus lucius | Colorado squawfish | 19.15 | | | | Excluded | D | Buhl 1997 |
| Ptychocheilus lucius | Colorado squawfish | 26.52 | 22.54 | | | Excluded | D | Buhl 1997 |
| Ptychocheilus oregonensis | Northern pike minnow | 2209 | | | | Excluded | D | Andros and Garton 1980 |
| Ptychocheilus oregonensis | Northern pike minnow | 2234 | 2221 | | | Excluded | D | Andros and Garton 1980 |
| Gila elegans | Bonytail | 36.34 | | | | Excluded | D | Buhl 1997 |
| Gila elegans | Bonytail | 41.25 | 38.72 | | | Excluded | D | Buhl 1997 |
| Catostomus commersoni | White sucker | 3136 | 3136 | | | Excluded | E | Duncan and Klaverkamp 1983 |
| Catostomus commersoni | White sucker | | | 7.804 | | Included | A | Eaton *et al.*, 1978 |
| Xyrauchen texanus | Razorback sucker | 34.13 | | | | Excluded | D | Buhl 1997 |
| Xyrauchen texanus | Razorback sucker | 39.29 | 36.62 | | | Excluded | D | Buhl 1997 |
| Ictalurus punctatus | Channel catfish | 5055 | 5055 | | | Excluded | D | Phipps and Holcombe 1985 |
| Jordanella floridae | Flagfish | 2847 | 2847 | | | Excluded | D | Spehar 1976 a,b |
| Gambusia affinis | Mosquitofish | 4157 | | | | Excluded | D | Giesy *et al.* 1977 |
| Gambusia affinis | Mosquitofish | 10161 | 6499 | | | Excluded | D | Giesy *et al.* 1977 |
| Poecilia reticulata | Guppy | 3224 | | | | Excluded | D | Pickering and Henderson 1966 |
| Poecilia reticulata | Guppy | 1787 | | | | Excluded | D | Canton and Slooff 1982 |
| Poecilia reticulata | Guppy | 2591 | 2462 | | | Excluded | D | Canton and Slooff 1982 |

## Table IX.8-3
## Cadmium Toxicity Database (Continued)

| Species | Common Name | $LC_{50}$ or $EC_{50}$ Adjusted to 50 mg/L Hardness | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L Hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | References |
|---|---|---|---|---|---|---|---|---|
| Gasterosteus aculeatus | Threespine stickleback | 2787 | | | | Included | A | Pascoe and Cram 1977 |
| Gasterosteus aculeatus | Threespine stickleback | 10613 | 5439 | | | Included | A | Pascoe and matty 1977 |
| Morone saxatilis | Striped bass | 1.458 | | | | Excluded | D | Hughes 1973 |
| Morone saxatilis | Striped bass | 2.917 | | | | Excluded | D | Hughes 1973 |
| Morone saxatilis | Striped bass | 5.019 | | | | Excluded | D | Palawski *et al.* 1985 |
| Morone saxatilis | Striped bass | 1.704 | 2.925 | | | Excluded | D | Palawski *et al.* 1985 |
| Lepomis cyanellus | Green sunfish | 7208 | | | | Excluded | D | Pickering and Henderson 1966 |
| Lepomis cyanellus | Green sunfish | 8871 | | | | Excluded | D | Pickering and Henderson 1966 |
| Lepomis cyanellus | Green sunfish | 6677 | | | | Excluded | D | Carrier and Beitinger 1988b |
| Lepomis cyanellus | Green sunfish | 2965 | 2965 | | | Excluded | D | Jude 1973 |
| Lepomis macrochirus | Bluegill | 4924 | | | | Excluded | D | Pickering and Henderson 1966 |
| Lepomis macrochirus | Bluegill | 6498 | | | | Excluded | D | Bishop and McIntosh 1981 |
| Lepomis macrochirus | Bluegill | 6498 | | | | Excluded | D | Bishop and McIntosh 1981 |
| Lepomis macrochirus | Bluegill | 4978 | | | | Excluded | D | Eaton 1980 |
| Lepomis macrochirus | Bluegill | 7300 | 6028 | | | Excluded | D | Phipps and Holcombe 1985 |
| Oreochromis mossambica | Tilapia | 10663 | 10663 | | | Excluded | D | Gaikwad 1989 |

## Table IX.8-3
## Cadmium Toxicity Database (Continued)

| Species | Common Name | $LC_{50}$ or $EC_{50}$ Adjusted to 50 mg/L Hardness | Species Mean Acute Value at Hardness of 50 mg/L | Measured Chronic Value (µg/L) at 50 mg/L Hardness | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | References |
|---|---|---|---|---|---|---|---|---|
| Xenopus laevis | African clawed frog | 1529 | 1529 | | | Excluded | D | Sunderman *et al.* 1991 |
| Ambystoma gracile | Salamander | 521.4 | 521.4 | | | Excluded | D | Nebekker *et al.* 1995 |

[1]Reasons for inclusion or exclusion:

**A** - Toxicity data on species that are known to occur or may occur at the site can not be excluded.

**B** - If a member of a family of freshwater fish may occur at the site, then toxicity data from any fish species within that family is maintained in the database.

**C** - If a member of a class of freshwater invertebrates may occur at the site, then all toxicity data from that invertebrate class is retained in the toxicity database.

**D** - Toxicity data on species that are not known to occur or are not likely to occur at the site are excluded.

**E** - Data was excluded for acute toxicity measurements if measured chronic values were available for the species.

**F** - Most sensitive life stage included.

**G** - May already be represented.

# Table IX.8-4
# Cadmium Toxicity Data for the Development of the Species Sensitivities Distributions

| Species | Common Name | Selected Chronic Value at 180 mg/L Hardness | Percent Community Affected |
|---|---|---|---|
| Hyalella azteca | Amphipod | *0.70* | 2.44 |
| Simocephalus serrulatus | Cladoceran | 0.75 | 4.88 |
| Daphnia magna | Cladoceran | ***0.79***[a] | 7.32 |
| Ceriodaphnia reticulata | Cladoceran | *1.02* | 9.76 |
| Lirceus alabamae | Isopod | 1.20 | 12.20 |
| Oncorhynchus mykiss | Rainbow trout | 3.38 | 14.63 |
| Salvelinus confluentus | Bull trout | 5.10 | 17.07 |
| Cyclops varicans | Copepod | 5.53 | 19.51 |
| Salvelinus fontinalis | Brook trout | ***6.05***[b] | 21.95 |
| Alona affinis | Cladoceran | 6.12 | 24.39 |
| Oncorhynchus tshawytscha | Chinook salmon | 6.75 | 26.83 |
| Chironomus tentans | Midge | *7.23* | 29.27 |
| Oncorhynchus kisutch | Coho salmon | 11.02 | 31.71 |
| Asellus bicrenata | Isopod | 11.69 | 34.15 |
| Aplexa hypnorum | Snail | ***12.45***[c] | 36.59 |
| Physa gyrina | Snail | 12.47 | 39.02 |
| Salmo trutta | Brown trout | 15.64 | 41.46 |
| Daphnia pulex | Cladoceran | *15.93* | 43.90 |
| Lumbriculus variegatus | Worm (Adult) | 16.25 | 46.34 |
| Catostomus commersoni | White sucker | *20.15* | 48.78 |
| Salmo salar | Atlantic salmon | *20.46* | 51.22 |
| Salvelinus namaycush | Lake trout | *20.89* | 53.66 |
| Esox lucius | Northern pike | *20.90* | 56.10 |
| Gossiponia complanta | Leech | 23.95 | 58.54 |
| Aeolosoma headleyi | worm | *53.58* | 60.98 |
| Ceriodaphnia dubia | Cladoceran | 70.19 | 63.41 |
| Limnodrilus hoffmeisteri | Tubificid worm | 96.44 | 65.85 |
| Tubifex tubifex | Tubificid worm | 169.35 | 68.29 |
| Crangonyx pseudogracilis | Amphipod | 211.54 | 70.73 |
| Ephemerella grandis | Mayfly | 283.46 | 73.17 |
| Branchiura sowerbyi | Tubificid worm | 292.42 | 75.61 |
| Quistadrilus multisetosus | Tubificid worm | 389.85 | 78.05 |
| Spirosperma ferox | Tubificid worm | 426.43 | 80.49 |
| Varichaeta pacifica | Tubificid worm | 463.02 | 82.93 |
| Spirosperma nikolskyi | Tubificid worm | 548.25 | 85.37 |
| Stylodrilus heringlianus | Tubificid worm | 670.20 | 87.80 |
| Rhyacodrilus montana | Tubificid worm | 767.63 | 90.24 |
| Gammarus pseudolimnaeus | Amphipod | 979.17 | 92.68 |

## Table IX.8-4
## Cadmium Toxicity Data for the Development of the Species Sensitivities Distributions (Continued)

| Species | Common Name | Selected Chronic Value at 180 mg/L Hardness | Percent Community Affected |
|---|---|---|---|
| Gasterdosteus aculeatus | Threespine stickleback | 1070.09 | 95.12 |
| Dendrocoelum lacteum | Planarian | 1750.41 | 97.56 |
| Chironomus riparius | Midge | 12055.11 | 100.00 |

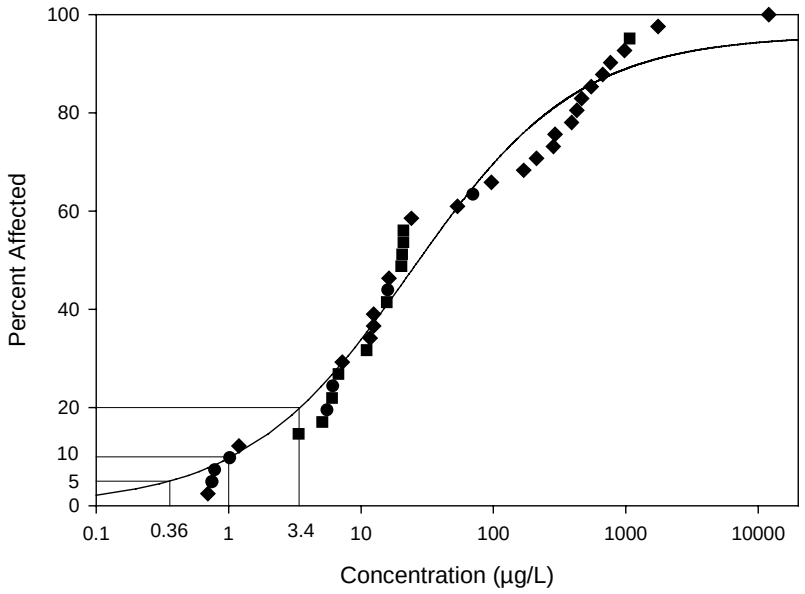
[1]Values in italics represent measured chronic values. All other values in this column represent predicted species mean chronic values.

[a]Bolded value is the geometric mean of four measured chronic values (*i.e.,* 0.15 µg/g, 0.12 µg/g, 0.15 µg/g and 3.13 µg/L) for this species.

[b]Bolded value is the geometric mean of three measured chronic values (*i.e.,* 2.17 µg/g, 2.25 µg/g, and 2.64 µg/L) for this species.

[c]Bolded value is the geometric mean of two measured chronic values (*i.e.,* 3.72 µg/g and 6.24 µg/L) for this species.

**Figure IX.8-2 Species Sensitivity Distribution for Cadmium. Based on Measured and Predicted Chronic Concentrations (● = cladocerans, ■ = fish, and ♦ = other invertebrates).**



As illustrated in Figure IX.8-2, the most sensitive species are cladocerans followed by other invertebrates and fish. However, there is a broad range of all three of these groups throughout the SSD.

A logistic regression was fit to the Cd data and is illustrated as a line on Figure IX.8-2. The results of the non-linear regression analysis indicated a good fit with a $r^2 = 0.97$. The resulting logisitic regression model was:

$$y = \frac{95.8057}{1+\left(\frac{x}{24.0681}\right)^{-0.6882}}$$

where y = percent of aquatic community affected; and x = concentration adjusted to hardness concentration of 180 mg/L.

Based on the above equation, appropriate Hazard concentrations were generated for 5, 10, and 20% affect levels. These concentrations are provided on Figure IX.8-2. Note that because of the conservative nature of the logisitic regression at the lower tail, the $HC_5$ concentration is lower than the measured lowest chronic effect concentrations. Hazard concentrations may be calculated at different hardness values using the standard hardness correction formula.

### 1.3.3 Hexavalent Chromium

The toxicity database generated for hexavalent chromium (Cr VI) is provided in Table IX.8-5 and consists of all toxicity information meeting either the CCME or U.S. EPA toxicity data requirements for acceptance, as well as species mean acute values, measured chronic values and calculated ACR. As indicated in the methodology above, not all species were considered to be appropriate for inclusion in the development of site-specific benchmarks for the Snap Lake Diamond Project. Toxicity data included or excluded from the database is indicated in Table IX.8-5. No hardness correction factors are available for Cr VI.

Species sensitivity distributions were generated from the data provided in Table IX.8-6. This included predicted species mean chronic values or measured chronic values, where available, and the cumulative probability (*i.e.*, percent affected) data.

# Table IX.8-5
# Hexavalent Chromium Toxicity Database

| Species | Common Name | $LC_{50}$ or $EC_{50}$ (µg/L) | Species Mean Acute Value (µg/L) | Measured Chronic Value (µg/L) | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | Reference |
|---|---|---|---|---|---|---|---|---|
| Physa herostropha | Snail | 16800 | | | | Included | A | Patrick *et al.* 1968 |
| Physa herostropha | Snail | 17300 | | | | Included | A | Academy of Natural Sciences 1960; Patrick *et al.* 1968 |
| Physa herostropha | Snail | 17300 | | | | Included | A | Academy of Natural Sciences 1960 |
| Physa herostropha | Snail | 40600 | | | | Included | A | Academy of Natural Sciences 1960 |
| Physa herostropha | Snail | 31600 | 23010 | | | Included | A | Academy of Natural Sciences 1960 |
| Ceriodaphnia dubia | Cladoceran | n/a | | 10 | | Included | C | Hickey 1989 |
| Ceriodaphnia reticulata | Cladoceran | 45.2 | | 40 | 1.13 | Included | C | Mount 1982 |
| Ceriodaphnia reticulata | Cladoceran | 45 | 45.1 | | | Included | C | Mount & Norberg 1984 |
| Daphnia magna | Cladoceran | 141 | | | | Included | A | Dowden & Bennett 1965 |
| Daphnia magna | Cladoceran | 3490 | | | | Included | A | Dowden & Bennett 1965 |
| Daphnia magna | Cladoceran | 212 | | | | Included | A | Call *et al.* 1981 |
| Daphnia magna | Cladoceran | 85.7 | | | | Included | A | Call *et al.* 1981 |
| Daphnia magna | Cladoceran | 19.9 | | | | Included | A | Call *et al.* 1981 |
| Daphnia magna | Cladoceran | 900 | | | | Included | A | Cairns *et al.* 1978 |
| Daphnia magna | Cladoceran | 50 | | <10 | >5 | Included | A | Trabalka & Gahrs 1997 |
| Daphnia magna | Cladoceran | 175 | | | | Included | A | White 1979 |
| Daphnia magna | Cladoceran | 157 | | | | Included | A | White 1979 |
| Daphnia magna | Cladoceran | 131 | | | | Included | A | Call *et al.* 1981 |
| Daphnia magna | Cladoceran | 73.6 | | | | Included | A | Call *et al.* 1981 |
| Daphnia magna | Cladoceran | 21.3 | | | | Included | A | Call *et al.* 1981 |
| Daphnia magna | Cladoceran | 137 | | | | Included | A | Call *et al.* 1981 |
| Daphnia magna | Cladoceran | 66.7 | | | | Included | A | Call *et al.* 1981 |
| Daphnia magna | Cladoceran | 15.3 | | | | Included | A | Call *et al.* 1981 |
| Daphnia magna | Cladoceran | 164 | | | | Included | A | Call *et al.* 1981 |

## Table IX.8-5
## Hexavalent Chromium Toxicity Database (Continued)

| Species | Common Name | $LC_{50}$ or $EC_{50}$ (µg/L) | Species Mean Acute Value (µg/L) | Measured Chronic Value (µg/L) | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | Reference |
|---|---|---|---|---|---|---|---|---|
| Daphnia magna | Cladoceran | 75.8 | | | | Included | A | Call *et al.* 1981 |
| Daphnia magna | Cladoceran | 20.6 | | | | Included | A | Call *et al.* 1981 |
| Daphnia magna | Cladoceran | 81 | | | | Included | A | Stephenson & Watts 1984 |
| Daphnia magna | Cladoceran | 110 | | | | Included | A | Stephenson & Watts 1984 |
| Daphnia magna | Cladoceran | 35 | | | | Included | A | Stephenson & Watts 1984 |
| Daphnia magna | Cladoceran | 24.2 | | <2.5 | >9.68 | Included | A | Mount 1982 |
| Daphnia magna | Cladoceran | 22 | 23.07 | | | Included | A | Mount & Norberg 1984 |
| Daphnia pulex | Cladoceran | 760 | | | | Included | C | Cairns *et al.* 1978 |
| Daphnia pulex | Cladoceran | 48 | | | | Included | C | Mount & Norberg 1984 |
| Daphnia pulex | Cladoceran | 36.3 | 36.3 | 6.132 | 5.92 | Included | C | Mount 1982 |
| Simocephalus serrulatus | Cladoceran | 40.9 | 40.9 | 19.9 | 2.055 | Included | C | Mount 1982 |
| Simocephalus vetulus | Cladoceran | 50 | | | | Included | C | Mount & Norberg 1984 |
| Simocephalus vetulus | Cladoceran | 32.3 | 32.3 | 6.132 | 5.267 | Included | C | Mount 1982 |
| Gammarus pseudolimnaeus | Amphipod | 101 | | | | Included | C | Call *et al.* 1981 |
| Gammarus pseudolimnaeus | Amphipod | 94.1 | | | | Included | C | Call *et al.* 1981 |
| Gammarus pseudolimnaeus | Amphipod | 67.1 | 67.1 | | | Included | C | Call *et al.* 1981 |
| Hyalella azteca | Amphipod | 630 | 630 | | | Included | C | Call *et al.* 1981 |
| Orconectes rusticus | Crayfish | 175000 | 176000 | | | Excluded | D | White Manuscript |
| Enallagma aspersum | Damselfly | 140000 | 140000 | | | Included | C | White Manuscript |
| Neophasganophora capitata | Stonefly | 1870000 | 1870000 | | | Included | C | White Manuscript |
| Chironomus tentans | Midge | 61000 | 61000 | | | Included | A | Batac-Catalan & White 1983 |
| Tanytarsus dissimilis | Midge | 57300 | 57300 | | | Included | C | Call *et al.* 1981 |
| Pectinatella magnifica | Bryozoan | 1440 | 1440 | | | Excluded | D | Pardue & Wood 1980 |
| Lophopodella carteri | Bryozoan | 1560 | 1560 | | | Excluded | D | Pardue & Wood 1980 |
| Plumatella emarginata | Bryozoan | 650 | 650 | | | Excluded | D | Pardue & Wood 1980 |
| Oncorhynchus mykiss | Rainbow trout | 69000 | 69000 | 264.6 | 260.8 | Included | B | Benoit 1976 |
| Oncorhynchus mykiss | Rainbow trout | n/a | | 73.18 | | Included | B | Sauter *et al.* 1976 |

## Table IX.8-5
## Hexavalent Chromium Toxicity Database (Continued)

| Species | Common Name | $LC_{50}$ or $EC_{50}$ (µg/L) | Species Mean Acute Value (µg/L) | Measured Chronic Value (µg/L) | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | Reference |
|---|---|---|---|---|---|---|---|---|
| Salvelinus fontinalis | Brook trout | 59000 | 59000 | 264.6 | 223 | Included | B | Benoit 1976 |
| Campostoma anomalum | Central stoneroller | 51250 | 51250 | | | Excluded | D | White Manuscript |
| Carassius auratus | Goldfish | 37500 | | | | Excluded | D | Pickering & Henderson 1966 |
| Carassius auratus | Goldfish | 110000 | | | | Excluded | D | Riva *et al.* 1981 |
| Carassius auratus | Goldfish | 123000 | | | | Excluded | D | Adelman & Smith 1976 |
| Carassius auratus | Goldfish | 123000 | | | | Excluded | D | Adelman & Smith 1976 |
| Carassius auratus | Goldfish | 90 | | | | Excluded | D | Adelman & Smith 1976 |
| Carassius auratus | Goldfish | 125000 | | | | Excluded | D | Adelman & Smith 1976 |
| Carassius auratus | Goldfish | 109000 | | | | Excluded | D | Adelman & Smith 1976 |
| Carassius auratus | Goldfish | 135000 | | | | Excluded | D | Adelman & Smith 1976 |
| Carassius auratus | Goldfish | 110000 | | | | Excluded | D | Adelman & Smith 1976 |
| Carassius auratus | Goldfish | 129000 | | | | Excluded | D | Adelman & Smith 1976 |
| Carassius auratus | Goldfish | 98000 | | | | Excluded | D | Adelman & Smith 1976 |
| Carassius auratus | Goldfish | 133000 | | | | Excluded | D | Adelman & Smith 1976 |
| Carassius auratus | Goldfish | 102000 | | | | Excluded | D | Adelman & Smith 1976 |
| Carassius auratus | Goldfish | 133000 | | | | Excluded | D | Adelman & Smith 1976 |
| Carassius auratus | Goldfish | 126000 | | | | Excluded | D | Adelman & Smith 1976 |
| Carassius auratus | Goldfish | 126000 | | | | Excluded | D | Adelman & Smith 1976 |
| Carassius auratus | Goldfish | 133000 | | | | Excluded | D | Adelman & Smith 1976 |
| Carassius auratus | Goldfish | 126000 | | | | Excluded | D | Adelman & Smith 1976 |
| Carassius auratus | Goldfish | 124000 | 119500 | | | Excluded | D | Adelman & Smith 1976 |
| Ericymba buccata | Silverjaw minnow | 49600 | 49600 | | | Excluded | D | White Manuscript |
| Notropis atherinoides | Emerald shiner | 48400 | 48400 | | | Included | A | White Manuscript |
| Notropis chrysocephalus | Striped shiner | 85600 | 85600 | | | Excluded | D | White Manuscript |
| Notropis stramineus | Sand shiner | 74600 | 74600 | | | Excluded | D | White Manuscript |
| Pimephales notatus | Bluntnose minnow | 54225 | 54225 | | | Excluded | D | White Manuscript |
| Pimephales promelas | Fathead minnow | 58000 | | | | Excluded | D | White Manuscript |

## Table IX.8-5
## Hexavalent Chromium Toxicity Database (Continued)

| Species | Common Name | $LC_{50}$ or $EC_{50}$ (µg/L) | Species Mean Acute Value (µg/L) | Measured Chronic Value (µg/L) | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | Reference |
|---|---|---|---|---|---|---|---|---|
| Pimephales promelas | Fathead minnow | 39700 | | | | Excluded | D | Pickering 1980 |
| Pimephales promelas | Fathead minnow | 32700 | | | | Excluded | D | Pickering 1980 |
| Pimephales promelas | Fathead minnow | 17600 | | | | Excluded | D | Pickering & Henderson 1966 |
| Pimephales promelas | Fathead minnow | 27300 | | | | Excluded | D | Pickering & Henderson 1966 |
| Pimephales promelas | Fathead minnow | 45600 | | | | Excluded | D | Pickering & Henderson 1966 |
| Pimephales promelas | Fathead minnow | 56000 | | | | Excluded | D | Adelman & Smith 1976 |
| Pimephales promelas | Fathead minnow | 51000 | | | | Excluded | D | Adelman & Smith 1976 |
| Pimephales promelas | Fathead minnow | 53000 | | | | Excluded | D | Adelman & Smith 1976 |
| Pimephales promelas | Fathead minnow | 49000 | | | | Excluded | D | Adelman & Smith 1976 |
| Pimephales promelas | Fathead minnow | 48000 | | | | Excluded | D | Adelman & Smith 1976 |
| Pimephales promelas | Fathead minnow | 60000 | | | | Excluded | D | Adelman & Smith 1976 |
| Pimephales promelas | Fathead minnow | 50000 | | | | Excluded | D | Adelman & Smith 1976 |
| Pimephales promelas | Fathead minnow | 53000 | | | | Excluded | D | Adelman & Smith 1976 |
| Pimephales promelas | Fathead minnow | 49000 | | | | Excluded | D | Adelman & Smith 1976 |
| Pimephales promelas | Fathead minnow | 37000 | | | | Excluded | D | Adelman & Smith 1976 |
| Pimephales promelas | Fathead minnow | 66000 | | | | Excluded | D | Adelman & Smith 1976 |
| Pimephales promelas | Fathead minnow | 55000 | | | | Excluded | D | Adelman & Smith 1976 |
| Pimephales promelas | Fathead minnow | 38000 | | | | Excluded | D | Adelman & Smith 1976 |
| Pimephales promelas | Fathead minnow | 34000 | | | | Excluded | D | Adelman & Smith 1976 |
| Pimephales promelas | Fathead minnow | 29000 | | | | Excluded | D | Adelman & Smith 1976 |
| Pimephales promelas | Fathead minnow | 34000 | | | | Excluded | D | Adelman & Smith 1976 |
| Pimephales promelas | Fathead minnow | 26000 | | | | Excluded | D | Adelman & Smith 1976 |
| Pimephales promelas | Fathead minnow | 33200 | | | | Excluded | D | Borderius & Smith 1979 |
| Pimephales promelas | Fathead minnow | 37700 | | | | Excluded | D | Pickering 1980 |
| Pimephales promelas | Fathead minnow | 37000 | | | | Excluded | D | Pickering 1980 |
| Pimephales promelas | Fathead minnow | 35900 | | | | Excluded | D | Pickering 1980 |
| Pimephales promelas | Fathead minnow | 52000 | | | | Excluded | D | Ruesink & Smith 1975 |

## Table IX.8-5
## Hexavalent Chromium Toxicity Database (Continued)

| Species | Common Name | $LC_{50}$ or $EC_{50}$ (µg/L) | Species Mean Acute Value (µg/L) | Measured Chronic Value (µg/L) | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | Reference |
|---|---|---|---|---|---|---|---|---|
| Pimephales promelas | Fathead minnow | 37000 | | | | Excluded | D | Ruesink & Smith 1975 |
| Pimephales promelas | Fathead minnow | 24140 | | | | Excluded | D | Waheda 1977 |
| Pimephales promelas | Fathead minnow | 22580 | | | | Excluded | D | Waheda 1977 |
| Pimephales promelas | Fathead minnow | 61000 | | | | Excluded | D | Ruesink & Smith 1975 |
| Pimephales promelas | Fathead minnow | 58000 | | | | Excluded | D | Ruesink & Smith 1975 |
| Pimephales promelas | Fathead minnow | 52000 | 40945 | | | Excluded | D | Ruesink & Smith 1975 |
| Poecilia reticulata | Guppy | 30000 | 30000 | | | Excluded | D | Pickering & Henderson 1966 |
| Morone saxatilis | Striped bass | 35000 | | | | Excluded | D | Hughes 1973 |
| Morone saxatilis | Striped bass | 26500 | 30450 | | | Excluded | D | Hughes 1973 |
| Lepomis cyanellus | Green sunfish | 89160 | | | | Excluded | D | Waheda 1977 |
| Lepomis cyanellus | Green sunfish | 147560 | 114700 | | | Excluded | D | Waheda 1977 |
| Lepomis macrochirus | Bluegill | 118000 | | | | Excluded | D | Pickering & Henderson 1966 |
| Lepomis macrochirus | Bluegill | 133000 | | | | Excluded | D | Pickering & Henderson 1966 |
| Lepomis macrochirus | Bluegill | 110000 | | | | Excluded | D | Trama & Benoit 1960 |
| Lepomis macrochirus | Bluegill | 170000 | | | | Excluded | D | Trama & Benoit 1960 |
| Lepomis macrochirus | Bluegill | 113000 | | | | Excluded | D | Cairns & Scheler 1958, 1959, 1968; Patrick *et al.* 1968 |
| Lepomis macrochirus | Bluegill | 113000 | | | | Excluded | D | Cairns & Scheier 1959 |
| Lepomis macrochirus | Bluegill | 113000 | | | | Excluded | D | Cairns & Scheier 1959 |
| Lepomis macrochirus | Bluegill | 120000 | | | | Excluded | D | Cairns & Scheier 1959 |
| Lepomis macrochirus | Bluegill | 168800 | | | | Excluded | D | Cairns & Sheier 1959; Patrick *et al.* 1968 |
| Lepomis macrochirus | Bluegill | 147000 | | | | Excluded | D | Cairns & Scheier 1959 |
| Lepomis macrochirus | Bluegill | 135000 | | | | Excluded | D | Academy of Natural Sciences 1960 |
| Lepomis macrochirus | Bluegill | 130400 | | | | Excluded | D | Academy of Natural Sciences 1960 |
| Lepomis macrochirus | Bluegill | 144500 | | | | Excluded | D | |
| Lepomis macrochirus | Bluegill | 132890 | 132900 | | | Excluded | D | Cairns *et al.* 1981 |

## Table IX.8-5
## Hexavalent Chromium Toxicity Database (Continued)

| Species | Common Name | $LC_{50}$ or $EC_{50}$ (µg/L) | Species Mean Acute Value (µg/L) | Measured Chronic Value (µg/L) | Acute-Chronic Ratio | Site-Specific Screening | Reason for Inclusion or Exclusion[1] | Reference |
|---|---|---|---|---|---|---|---|---|
| Pomoxis annularis | White crappie | 72600 | 72600 | | | Excluded | D | White Manuscript |
| Etheostoma nigrum | Johnny darter | 46000 | 46000 | | | Excluded | D | White Manuscript |
| Perca flavescens | Yellow perch | 36300 | 36300 | | | Excluded | D | White Manuscript |
| Aedes aegypti | Yellow fever mosquito | 12500 | 12500 | | | Excluded | D | Abbasi *et al.* 1988 |
| Cyprinus carpio | Common, mirror, colored, carp | 93600 | 93600 | | | Excluded | D | Al Akel and Shamsi 1996 |
| Gammarus fossarum | Amphipod | 1370 | 1370 | 190 | 7.21 | Included | A | Canivet *et al.* 2001 |
| Asellus aquatics | Isopod | 14000 | 14000 | 510 | 27.45 | Included | C | Canivet *et al.* 2001 |
| Heptagenia sulphurea | Mayfly | 3800 | | 220 | 17.27 | Included | C | Canivet *et al.* 2001 |
| Heptagenia sulphurea | Mayfly | 3970 | 3884 | | | Included | C | Canivet *et al.* 2001 |
| Hydropsiche pellucidula | Caddisfly | 31000 | 31000 | 4800 | 6.46 | Included | C | Canivet *et al.* 2001 |
| Physa fontinalis | snail | 9460 | | 4200 | 2.25 | Included | A | Canivet *et al.* 2001 |
| Physa fontinalis | snail | 9420 | 9440 | | | Included | A | Canivet *et al.* 2001 |

[1]Reasons for inclusion or exclusion:

**A** - Toxicity data on species that are known to occur or may occur at the site can not be excluded.

**B** - If a member of a family of freshwater fish may occur at the site, then toxicity data from any fish species within that family is maintained in the database.

**C** - If a member of a class of freshwater invertebrates may occur at the site, then all toxicity data from that invertebrate class is retained in the toxicity database.

**D** - Toxicity data on species that are not known to occur or are not likely to occur at the site are excluded.

**E** - Data was excluded for acute toxicity measurements if measured chronic values were available for the species.

**F** - Most sensitive life stage included.

**G** - May already be represented.

< indicates that effects were measured at the lowest concentration tested therefore the effect level is less than the shown value

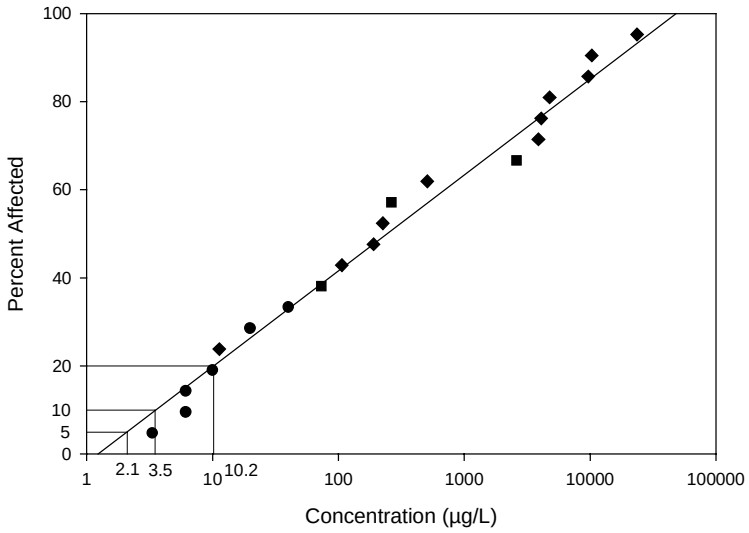
**Table IX.8-6**
**Hexavalent Chromium Toxicity Data for the Development of Species Sensitivities Distributions**

| Species | Common Name | Chronic Value (µg/L)[1] | Percent Community Affected |
|---|---|---|---|
| Daphnia magna | Cladoceran | 3.32 | 4.76 |
| Daphnia pulex | Cladoceran | 6.13 | 9.52 |
| Simocephalus vetulus | Cladoceran | 6.13 | 14.29 |
| Ceriodaphnia dubia | Cladoceran | *10.00* | 19.05 |
| Gammarus pseudolimnaeus | Amphipod | 11.33 | 23.81 |
| Simocephalus serrulatus | Cladoceran | 19.90 | 28.57 |
| Ceriodaphnia reticulata | Cladoceran | 40.00 | 33.33 |
| Oncorhynchus mykiss | Rainbow trout | *73.18* | 38.10 |
| Hyalella azteca | Amphipod | 106.42 | 42.86 |
| Gammarus fossarum | Amphipod | 190.28 | 47.62 |
| Heptagenia sulphurea | Mayfly | 225.43 | 52.38 |
| Salvelinus fontinalis | Brook trout | 264.57 | 57.14 |
| Asellus aquatics | Isopod | 509.09 | 61.90 |
| Notropis atherinoides | Emerald shiner | 2609.16 | 66.67 |
| Physa herostropha | Snail | 3886.82 | 71.43 |
| Physa fontinalis | Snail | 4086.96 | 76.19 |
| Hydropsiche pellucidula | Caddisfly | 4769.23 | 80.95 |
| Tanytarsus dissimilis | Midge | 9679.05 | 85.71 |
| Chironomus tentans | Midge | 10304.05 | 90.48 |
| Enallagma aspersum | Damselfly | 23648.65 | 95.24 |
| Neophasganophora capitata | Stonefly | 108092.49 | 100 |

[1]Values in italics represent measured chronic values. All other values in this column represent predicted species mean chronic values.

The SSD for Cr VI is provided in Figure IX.8-3. The concentration data is plotted on a lognormal scale with the cumulative probability expressed as a percentage.

**Figure IX.8-3 Hexavalent Chromium Species Sensitivity Distribution Based on Measured or Predicted Chronic Concentrations (●= cladocerans, ■= fish and ♦= other invertebrates).**




The chronic concentrations and percent affected data Cr VI was fit to a linear regression model resulting in an $r^2$=0.98 for the linear regression model:

$$y = 21.78 * \log_{10} * (x) - 1.96$$

where y = percent of aquatic community affected; and x = concentration (µg/L).

Based on the above equation, Hazard concentrations were generated for 5, 10, and 20% affect levels at concentrations of 2.1, 3.5 and 10.2 µg/L, respectively. These concentrations are provided on Figure IX.8-3. As with previous parameters, the $HC_5$ value is lower than the lowest chronic value used within this data set and is therefore protective to most species at the standardized endpoints.

Hazard concentrations may be calculated at different hardness values using the standard hardness correction formula.

### 1.3.4 Trivalent Chromium

The toxicity database generated for trivalent chromium (Cr III) is provided in Table IX.8-7 and consists of all toxicity information meeting either the CCME or U.S. EPA toxicity data requirements for acceptance, as well as species mean acute values, measured chronic values and calculated ACR. As indicated in the methodology above, not all species were considered to be appropriate for inclusion in the development of site-specific benchmarks for the Snap Lake Diamond Project. Toxicity data excluded from the database is indicated in Table IX.8-7. The U.S. EPA (1984b) provides a hardness correction factor for Cr III, therefore, Cr III was standardized to a hardness of 50 mg/L in Table IX.8-7. The equation is the same as noted above with the slope factor for both the acute and chronic conversions equal to 0.8190.

Species sensitivity distributions were generated from the data provided in Table IX.8-8. The selected chronic toxicity data was adjusted to a hardness of 180 mg/L. Information in Table IX.8-8 includes species identification, predicted and measured chronic values, and the cumulative probability (*i.e.*, percent affected) data.

The SSD for Cr III is provided in Figure IX.8-4. The concentration data is plotted on a lognormal scale with the cumulative probability expressed as a percentage.

# Table IX.8-7
# Trivalent Chromium Toxicity Database

| | | | LC50 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | **Common Name** | **Hardness (mg/L as CaCO3)** | **Reported** | **Adjusted to Hardness of 50 mg/L** | **Adjusted Species Mean Acute Value (µg/L)** | **Measured Chronic Value (µg/L) Adjusted to Hardness 50 mg/L** | **Acute-Chronic Ratio** | **Site-Specific Screening** | **Reason for Inclusion or Exclusion [1]** | **Reference** |
| Nais sp | Worm | 50 | 9300 | 9300 | 9300 | | | Included | A | Rehwoldt *et al.* 1973 |
| Amnicola sp | Snail | 50 | 12400 | 12400 | | | | Included | A | Rehwoldt *et al.* 1973 |
| Amnicola sp | Snail | 50 | 8400 | 8400 | 10210 | | | Included | A | Rehwoldt *et al.* 1973 |
| Daphnia magna | Cladoceran | | 1200 | | | | | Excluded | E | Anderson 1948 |
| Daphnia magna | Cladoceran | 52 | 16800 | 16269 | | 64.0 | 254.1 | Included | A | Chapman *et al.* Manuscript |
| Daphnia magna | Cladoceran | 99 | 27400 | 15660 | | 110.7 | 141.5 | Included | A | Chapman *et al.* Manuscript |
| Daphnia magna | Cladoceran | 110 | 26300 | 13788 | | | | Excluded | E | Chapman *et al.* Manuscript |
| Daphnia magna | Cladoceran | 195 | 51400 | 16861 | | | | Excluded | E | Chapman *et al.* Manuscript |
| Daphnia magna | Cladoceran | 215 | 58700 | 17776 | 16010 | | | Excluded | E | Chapman *et al.* Manuscript |
| Daphnia magna | Cladoceran | 206 | 55380 | | | | | Excluded | E | Chapman *et al.* Manuscript |
| Gammarus sp | Amphipod | 50 | 3200 | 3200 | 3200 | | | Included | A | Rehwoldt *et al.* 1973 |
| Orconectus llmosus | Crayfish | | 6600 | | | | | Excluded | D | Boutet and Chaisemartin 1973 |
| Ephemerella subverla | Mayfly | 44 | 2000 | 2221 | 2221 | | | Included | C | Warnick and Bell 1969 |
| Unidentified | Damselfly | 50 | 43100 | 43100 | 43100 | | | Excluded | D | Rehwoldt *et al.* 1973 |
| Hydropsyche betteni | Caddisfly | 44 | 64000 | 71064 | 71060 | | | Included | C | Warnick and Bell 1969 |
| Unidentified | Caddisfly | 50 | 50000 | 50000 | 50000 | | | Excluded | G | Rehwoldt *et al.* 1973 |
| Tubifex tubifex | worm | 50 | 2910 | 2910 | 2910 | | | Included | A | Fargasova 1994 |
| Chironomus sp | Midge | 50 | 11000 | 11000 | 11000 | | | Included | A | Rehwoldt *et al.* 1973 |
| Angulla rostrata | American eel | 55 | 13900 | 12856 | 12860 | | | Excluded | D | Rehwoldt *et al.* 1972 |
| Oncorhynchus mykiss | Rainbow trout | | 24100 | | | | | Excluded | E | Hale 1977 |
| Oncorhynchus mykiss | Rainbow trout | 44 | 11200 | 12436 | | | | Excluded | E | Bills *et al.* 1977; Marking 1982 |
| Oncorhynchus mykiss | Rainbow trout | 26 | 4400 | 7517 | 9669 | 117.2 | 64.1 | Included | B | Stevens and Chapman 1984 |
| Oncorhynchus kisutch | Coho Salmon | 50 | 28400 | 28400 | 28400 | | | Included | C | Holland *et al.* 1960 |
| Carassius auratus | Gold fish | 20 | 4100 | 8684 | 8684 | | | Excluded | D | Pickering and Henderson 1966 |

# Table IX.8-7
## Trivalent Chromium Toxicity Database (Continued)

| | | | LC50 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | **Common Name** | **Hardness (mg/L as CaCO3)** | **Reported** | **Adjusted to Hardness of 50 mg/L** | **Adjusted Species Mean Acute Value (µg/L)** | **Measured Chronic Value (µg/L) Adjusted to Hardness 50 mg/L** | **Acute-Chronic Ratio** | **Site-Specific Screening** | **Reason for Inclusion or Exclusion [1]** | **Reference** |
| Cyprinus carpio | Common carp | 55 | 14300 | 13226 | 13230 | | | Excluded | D | Rehwoldt *et al.* 1972 |
| Pimephales promelas | Fathead minnow | 20 | 5070 | 10738 | | | | Excluded | D | Pickering and Henderson 1966 |
| Pimephales promelas | Fathead minnow | 360 | 67400 | 13381 | | | | Excluded | D | Pickering and Henderson 1966 |
| Pimephales promelas | Fathead minnow | 203 | 29000 | 9205 | | | | Excluded | D | Pickering Manuscript |
| Pimephales promelas | Fathead minnow | 203 | 27000 | 8570 | 10320 | 325.3 | 27.3 | Excluded | D | Pickering Manuscript |
| Fundulus diaphanus | Banded killfish | 55 | 16900 | 15631 | 15630 | | | Excluded | D | Rehwoldt *et al.* 1972 |
| Poeclila reticulata | Guppy | 20 | 3330 | 7053 | 7053 | | | Excluded | D | Pickering and Henderson 1966 |
| Morone americana | White perch | 55 | 14400 | 13319 | 13320 | | | Excluded | D | Rehwoldt *et al.* 1972 |
| Morone saxatilis | Striped bass | 55 | 17700 | 16371 | 16370 | | | Excluded | D | Rehwoldt *et al.* 1972 |
| Lepomis gibbosus | Pumpkinseed | 55 | 17000 | 15723 | 15720 | | | Excluded | D | Rehwoldt *et al.* 1972 |
| Lepomis macrochirus | Bluegill | 20 | 7460 | 15800 | | | | Excluded | D | Pickering and Henderson 1966 |
| Lepomis macrochirus | Bluegill | 360 | 71900 | 14275 | 15020 | | | Excluded | D | Pickering and Henderson 1966 |
| Cyclops | Cyclopoid copepod | | 10470 | | 10470 | | | Included | C | Abbasi *et al.* 1988 |
| Daphnia pulex | Cladoceran | | 90400 | | 90400 | | | Included | C | Stackhouse & Benson 1989 |

[1]Reasons for inclusion or exclusion:

**A** - Toxicity data on species that are known to occur or may occur at the site can not be excluded.

**B** - If a member of a family of freshwater fish may occur at the site, then toxicity data from any fish species within that family is maintained in the database.

**C** - If a member of a class of freshwater invertebrates may occur at the site, then all toxicity data from that invertebrate class is retained in the toxicity database.

**D** - Toxicity data on species that are not known to occur or are not likely to occur at the site are excluded.

**E** - Data was excluded for acute toxicity measurements if measured chronic values were available for the species.

**F** - Most sensitive life stage included.

**G** - May already be represented.

**Table IX.8-8**
**Trivalent Chromium Toxicity Data for the Development of the Species Sensitivity Distributions**

| Species | common name | Selected Chronic Value at 180 mg/L Hardness[1] | Percent Community Affected |
|---|---|---|---|
| Ephemerella subverla | Mayfly | 98.78 | 8.33 |
| Tubifex tubifex | worm | 129.59 | 16.67 |
| Gammarus sp | Amphipod | 142.47 | 25.00 |
| Cyclops | Cyclopoid copepod | 157.66 | 33.33 |
| Oncorhynchus mykiss | Rainbow trout | *195.94* | 41.67 |
| Daphnia magna | Cladoceran | ***241.08***[a] | 50.00 |
| Nais sp | Worm | 413.98 | 58.33 |
| Amnicola sp | Snail | 454.66 | 66.67 |
| Chironomus sp | Midge | 489.87 | 75.00 |
| Oncorhynchus kisutch | Coho salmon | 1264.78 | 83.33 |
| Daphnia pulex | Cladoceran | 1361.28 | 91.67 |
| Hydropsyche betteni | Caddisfly | 3163.38 | 100.00 |

[1]Values in italics represent measured chronic values. All other values in this column represent predicted species mean chronic values.

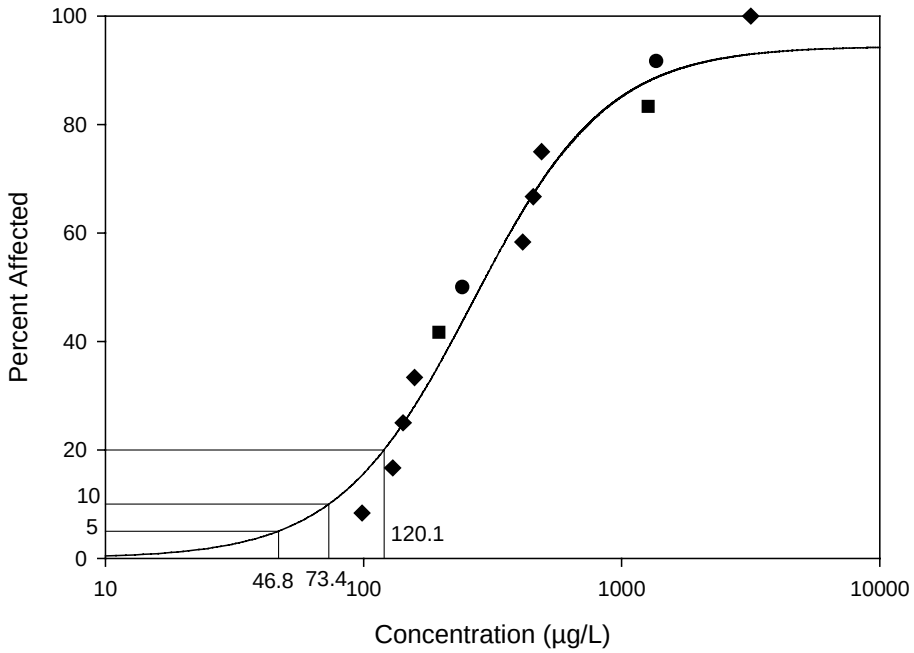
[a]Bolded value is the geometric mean of two measured chronic values (*i.e.,* 228.4 µg/g and 256.95 µg/L) for this species.

A logistic regression was fit to the Cd data and is illustrated as a line on Figure IX.8-4. The results of the non-linear regression analysis indicated a good fit with a $r^2 = 0.97$. The resulting logisitic regression model was:

$$y = \frac{94.4399}{1 + \left(\frac{x}{264.3948}\right)^{-1.6653}}$$

where y = percent of aquatic community affected; and x = concentration adjusted to hardness concentration of 180 mg/L.

**Figure IX.8-4 Trivalent Chromium Species Sensitivity Distribution Based on Measured or Predicted Chronic Concentrations (●= cladocerans, ■= fish and ♦= other invertebrates).**




Based on the above equation, appropriate Hazard concentrations were generated for 5, 10, and 20% affect levels. These concentrations are provided on Figure IX.8-2. Note that because of the conservative nature of the logisitic regression at the lower tail, the $HC_5$ and $HC_{10}$ concentration are both lower than the measured lowest chronic effect concentrations.

## 2.0 MINE WATER DISCHARGE TOXICITY TESTING

Toxicity testing was conducted on mine water samples collected as part of the advanced exploration program for the Snap Lake Diamond Project. Water samples from several locations were collected between March 31st and August 18th, 2001 (Table IX.8-9).

**Table IX.8-9**
**Sources of Advanced Exploration Mine Waters for Aquatic Toxicity Testing**

| Location Identifier | Location Description |
|---|---|
| Underground Mine Water | Water from the main storage sump in the underground workings that is collected at the end of the pipe from underground (underground mine water) before it enters the processed kimberlite containment |
| Discharge from the processed kimberlite containment pond to Snap Lake (end of pipe, start of pipe) | Samples collected within and at the end of the discharge pipe transporting water from the underground sumps to the processed kimberlite containment (end of pipe; start of pipe) |
| Processed kimberlite containment | Processed kimberlite containment, now called the water management pond |
| Mine Water | Archived underground mine water collected on August 11, 2001 from underground mine water location |
| Treated Mine water | Archived underground mine water treated with a flocculent and filtration treatment process |
| (HDS) Treated Mine Water | Archived underground mine water treated with a high-density sludge process |
| (PP8/HDS/$H_2O_2$) Treated Mine Water | Archived underground mine water treated with a high-density sludge process with the addition of hydrogen peroxide for sulphide removal |

Notes: HDS = high-density sludge; PP8/HDS/$H_2O_2$ = high-density sludge removal with hydrogen peroxide oxidation

### 2.1 Untreated Mine Water

Toxicity tests were conducted using a number of different test species. Initial acute tests were conducted with the End of Pipe (EOP)/Start of Pipe (SOP) samples between April 19th and May 28th, 2001. The *Oncorhynchus mykiss* (rainbow trout) and *Daphnia magna* acute test results indicate no observable effect concentrations (NOEC) at 100% mine water concentrations. No lethal concentrations (LC) were measured.

In April and July, 2001 additional water samples were collected from the Processed Kimberlite Containment (PKC). Samples from this location were tested for acute toxicity on rainbow trout and *Daphnia magna,* and chronic toxicity on *Selenastrum capricornutum, Ceriodaphnia dubia* and *Pimphales promelas* (fathead minnow). Although no acute toxicity was measured for any of the test species, chronic effects were reported for the three chronic test species (Table IX.8-10). Chronic endpoints were

growth and reproduction $IC_{25}$ that indicate a concentration where 25% of the organisms had inhibited reproduction or growth.

**Table IX.8-10**
**Acute and Chronic Toxicity Results from Mine Water Discharge Toxicity Test (Percent Mine Water) of Untreated Water from the Processed Kimberlite Containment Pond**

| | | | Chronic – Fecundity | | Chronic – Growth | | Acute | |
|---|---|---|---|---|---|---|---|---|
| **Sample Date** | **Location** | **Test Species** | **$IC_{25}$[1]** | **NOEC[2]** | **$IC_{25}$[1]** | **NOEC[2]** | **$LC_{50}$[3]** | **NOEC[2]** |
| April 7, 2001 | PKC | Trout | - | - | - | - | >100 | 100 |
| April 7, 2001 | PKC | Daphnia | - | - | - | - | >100 | 100 |
| July 10, 2001 | PKC | Selenastrum | - | - | 2 | <1.6 | n/a | n/a |
| July 10, 2001 | PKC | Ceriodaphnia | >100 | 50 | - | - | >100 | 100 |
| July 10, 2001 | PKC | Fathead minnow | - | - | 81 | 50 | >100 | 100 |
| July 10, 2001 | PKC | Trout | - | - | - | - | >100 | 100 |
| July 10, 2001 | PKC | Daphnia | - | - | - | - | >100 | 100 |

Notes: PKC = processed kimberlite containment; n/a = not applicable.
[1] $IC_{25}$ = inhibitive concentration that indicates a concentration where 25 percent of the organisms had inhibited reproduction or growth.
[2] NOEC = no observable effect concentration.
[3] $LC_{50}$ = median lethal concentration.

In August 2001 additional samples were collected from the UEOP location. The results of these toxicity tests indicated acute and chronic toxicity to various test species (Table IX.8-11). The initial toxicity was linked to elevated total suspended solids (TSS) in the sample therefore further tests were completed to evaluate toxicity with the TSS removed via increased dilutions and settling. The toxicity of the UEOP water remained at the lower limits of the settling and extended dilution water (Table IX.8-11).

## Table IX.8-11
## Acute and Chronic Mine Water Discharge Toxicity Test Results (Percent Mine Water)
## for Untreated Water Collected from the Underground Mine Water Location

| | | | Chronic – Fecundity | | Chronic – Growth | | Acute | |
|---|---|---|---|---|---|---|---|---|
| **Sample Date** | **Location** | **Test Species** | **$IC_{25}$[1]** | **NOEC[2]** | **$IC_{25}$** | **NOEC[2]** | **$LC_{50}$[3]** | **NOEC[2]** |
| July 8, 2001 | UEOP | Selenastrum | - | - | >100 | 100 | - | - |
| | | Ceriodaphnia | 52 | 50 | - | - | >100 | 100 |
| | | Fathead minnow | - | - | >100 | 100 | >100 | 100 |
| | | Trout | - | - | - | - | >100 | 100 |
| | | Daphnia | - | - | - | - | >100 | 100 |
| July 25, 2001 | UEOP | Selenastrum | - | - | >100 | 100 | - | - |
| | | Ceriodaphnia | <6.25 | <6.25 | - | - | <6.25 | <6.25 |
| | | Fathead minnow | - | - | 7 | 6.25 | 29 | 6.25 |
| | | Trout | - | - | - | - | 20 | 12.5 |
| | | Daphnia | - | - | - | - | <6.25 | <6.25 |
| August 15, 2001 | UEOP | Selenastrum | - | - | 23 | 12.5 | - | - |
| | | Ceriodaphnia | <6.25 | <6.25 | - | - | <6.25 | <6.25 |
| | | Fathead minnow | - | - | <6.25 | <6.25 | <6.25 | <6.25 |
| | | Trout | - | - | - | - | 20 | 12.5 |
| | | Daphnia | - | - | - | - | >100 | 100 |
| Sept. 25, 2001 | Mine water | Selenastrum | - | - | >100 | 100 | - | - |
| | | Ceriodaphnia | 27 | 12 | - | - | >100 | 100 |
| | | Fathead minnow | - | - | >100 | 100 | >100 | 100 |
| | | Trout | - | - | - | - | 80 | 50 |
| | | Daphnia | - | - | - | - | >100 | 100 |
| October 5, 2001 | UEOP settled (1) | Ceriodaphnia | 5 | <6.25 | - | - | >100 | 50 |
| | | fathead minnow | - | - | >100 | 100 | 81 | 50 |
| October 5, 2001 | UEOP settled (2) | Ceriodaphnia | 15 | 12.5 | - | - | 65 | 25 |
| | | fathead minnow | - | - | >100 | 100 | 81 | 25 |
| October 15, 2001 | UEOP diluted (1) | Ceriodaphnia | <0.38 | <0.38 | - | - | >6 | 6 |
| | | fathead minnow | - | - | >6 | 6 | >6 | 1.5 |
| | | Daphnia | - | - | - | - | >6 | 6 |
| October 15, 2001 | UEOP diluted (2) | Ceriodaphnia | <0.38 | <0.38 | - | - | >6 | 6 |
| | | Fathead minnow | - | - | >6 | 6 | >6 | 6 |

Notes: UEOP = underground mine water.

[1] $IC_{25}$ = inhibitive concentration that indicates a concentration where 25 percent of the organisms had inhibited reproduction or growth.

[2] NOEC = no observable effect concentration.

[3] $LC_{50}$ = median lethal concentration.

## 2.2 Treated Mine Water

Based on the results of the UEOP toxicity tests, pilot scale treatment testing was undertaken improve the water quality and eliminate or reduce the toxicity of mine water that would be discharged to Snap Lake. A large volume mine water sample was collected on August 11, 2001. Several treatment options were piloted and toxicity tests were completed on treated mine water from three of the tests. The three tests included:

- the use of a flocculent with filtration;
- high-density sludge (HDS) removal; and,
- high-density sludge removal with hydrogen peroxide oxidation (PP8/HDS/$H_2O_2$).

The results of the toxicity tests on treated samples are provided in Table IX.8-12.

As a component of the treatment process, the selected flocculent (0.5% Percol 351) was also tested at a concentration of 10% for its potential acute and chronic toxicity. The results of the Percol 351 toxicity testing indicated that there was no acute or chronic response to the flocculent at a concentration of 10%. This concentration was considerably higher than what would be required in the flocculent with filtration treatment process.

**Table IX.8-12**
**Mine Water Discharge Toxicity Test Results (Percent Mine Water)**
**for Treated Mine Water**

| Sample Date | Location/ Treatment | Test Species | Chronic – Fecundity | | Chronic – Growth | | Acute | |
|---|---|---|---|---|---|---|---|---|
| | | | $IC_{25}$[1] | NOEC[2] | $IC_{25}$[1] | NOEC[2] | $LC_{50}$[3] | $NOEC_2$ |
| Aug 3, 2001 | Percol 351 | *Selenastrum* | - | - | >10 | 10 | - | - |
| | | *Ceriodaphnia* | >10 | 10 | - | - | >10 | 10 |
| | | Fathead minnow | - | - | >10 | 10 | >10 | 10 |
| | | Trout | - | - | - | - | >10 | 10 |
| | | *Daphnia magna* | - | - | - | - | >10 | 10 |
| Nov 8, 2001 | Untreated Mine water (control) | *Selenastrum* | - | - | >100 | 100 | - | - |
| | | *Ceriodaphnia* | 20 | 12.5 | - | - | >100 | 100 |
| | | Fathead minnow | - | - | >100 | 100 | >100 | 100 |
| | | *Daphnia pulex* | 32 | 25 | 66 | 50 | 50 | 6.25 |
| Nov 8, 2001 | Treated | *Selenastrum* | - | - | >100 | 100 | - | - |
| | | *Ceriodaphnia* | 57 | 50 | - | - | >100 | 100 |
| | | Fathead minnow | - | - | >100 | 100 | >100 | 100 |
| | | *Daphnia pulex* | 59 | 50 | 34 | 25 | >100 | 100 |
| Dec 17, 2001 | HDS[4] | *Selenastrum* | - | - | 9 | 6.3 | - | - |
| | | Fathead minnow | - | - | >100 | 100 | >100 | 100 |
| | | *Daphnia pulex* | 54 | 50 | >100 | 100 | 55 | <6.25 |
| | | Trout | - | - | - | - | >100 | 100 |
| | | *Daphnia magna* | - | - | - | - | 19.5 | 12.5 |
| Dec 17, 2001 | PP8/HDS/H 2O2[5] | *Selenastrum* | - | - | >100 | 100 | - | - |
| | | Fathead minnow | - | - | >100 | 100 | >100 | 100 |
| | | *Daphnia pulex* | 64 | 50 | 72 | 50 | >100 | 100 |
| | | Trout | - | - | - | - | >100 | 100 |
| | | *Daphnia magna* | - | - | - | - | >100 | 100 |

Notes: [1] $IC_{25}$ = inhibitive concentration that indicates a concentration where 25 percent of the organisms had inhibited reproduction or growth.
[2] NOEC = no observable effect concentration.
[3] $LC_{50}$ = median lethal concentration.
[4] HDS = high-density sludge.
[5] PP8/HDS/$H_2O_2$ = high-density sludge removal with hydrogen peroxide oxidation.

The untreated mine water collected in August 2001 showed chronic toxicity to *Ceriodaphnia dubia* and both acute and chronic toxicity to *Daphnia pulex*. Following treatment through the flocculent with filtration (treated), the acute toxicity was removed and the chronic toxicity was greatly reduced. Other treatment options (HDS and the PP8/HDS/$H_2O_2$) showed similar results; however, some acute toxicity to Daphnia pulex persisted for the HDS treated water, which was removed in the PP8/HDS/$H_2O_2$ treatment process.

Water chemistry was obtained on the test waters for the chronic *Daphnia pulex* tests. This includes untreated settled mine water, treatment with flocculent and filtration, HDS treatment and PP8/HDS/$H_2O_2$ treatment. Water chemistry data is also available for the

untreated, unsettled mine water; however, toxicity tests were not run on this water because the TSS was elevated sufficiently to cause impairment to the test organisms. Chemical results are divided into routine parameters (Table IX.8-13) and metals (Table IX.8-14).

## Table IX.8-13
## Analytical Results for Routine Parameters Measured in Untreated and Treated Mine Water used in the Mine Water Discharge Toxicity Tests

| Parameter | Units | Detection Limit | Untreated Minewater | Untreated Supernatent | Treated (Flocculent & Filtration) | HDS[1] | PP8/HDS/$H_2O_2$[2] |
|---|---|---|---|---|---|---|---|
| **Routine Metals** | | | | | | | |
| Calcium (Ca) | mg/L | 0.05 | 122 | 122 | 205 | 123 | 240 |
| Potassium (K) | mg/L | 0.01 | 7.08 | 7.08 | 6.79 | 6.40 | 8.76 |
| Magnesium (Mg) | mg/L | 0.01 | 19.5 | 19.5 | 23.6 | 18.2 | 2.47 |
| Sodium (Na) | mg/L | 0.1 | 74.5 | 74.5 | 72.9 | 66.3 | 77.7 |
| **Ion Balance Calculation** | | | | | | | |
| Hardness | mg/L | | 385 | 392 | 609 | 382 | 609 |
| Ion balance | % | | 94.4 | 95.3 | 92.7 | 103 | 103 |
| **pH, Conductivity and Total Alkalinity** | | | | | | | |
| Alkalinity, Total | mg/L | 5 | 33 | 32 | 69 | 23 | 17 |
| Bicarbonate ($HCO_3$) | mg/L | 5 | 40 | 39 | 84 | 29 | 21 |
| Carbonate ($CO_3$) | mg/L | 5 | <5 | <5 | <5 | <5 | <5 |
| Conductivity (EC) | uS/cm | 0.2 | 1210 | 1220 | 1640 | 1230 | 1720 |
| Hydroxide | mg/L | 5 | <5 | <5 | <5 | <5 | <5 |
| pH | pH | 0.1 | 8.1 | 7.8 | 7.8 | 7.1 | 6.8 |
| **Other** | | | | | | | |
| Chloride (Cl) | mg/L | 1 | 333 | 335 | 330 | 245 | 360 |
| Nitrate+Nitrite-N | mg/L | 0.006 | 11.6 | 12.1 | 11.5 | 10.2 | 7.09 |
| Nitrate-N | mg/L | 0.006 | | | | 7.98 | 6.24 |
| Nitrite-N | mg/L | 0.002 | | | | 2.21 | 0.855 |
| Sulfate ($SO_4$) | mg/L | 0.05 | 42.8 | 43.5 | 251 | 125 | 220 |
| Ammonia-N | mg/L | 0.005 | 6.69 | 6.51 | 6.51 | 5.17 | 2.99 |
| Colour, True | TCU | 3 | 20 | 5 | 5 | 5 | 10 |
| Dissolved organic Carbon | mg/L | 1 | 2 | 2 | 2 | | |
| Fluoride (F) | mg/L | 0.05 | 1.1 | 1.1 | 1.11 | 0.86 | 0.55 |
| Oil and Grease | mg/L | 1 | <1 | <1 | <1 | <1 | <1 |
| Orthophosphate ($PO_4$) | mg/L | 0.001 | 0.02 | 0.006 | 0.005 | 0.013 | 0.008 |
| Phosphorus, Dissolved | mg/L | 0.001 | 0.015 | 0.005 | 0.008 | 0.019 | 0.039 |
| Phosphorus, Total | mg/L | 0.001 | 0.111 | 0.0009 | 0.009 | 0.020 | 0.049 |
| Silica, Reactive (as $SiO_2$) | mg/L | 0.1 | 22.8 | 22.5 | 11.9 | 3.9 | 1.4 |
| Total Dissolved Solids | mg/L | 10 | 1000 | 750 | 1290 | 660 | 980 |
| Total Kjeldahl Nitrogen | mg/L | 0.05 | 6.62 | 6.31 | 5.99 | 5.02 | 3.72 |
| Total Organic Carbon | mg/L | 1 | 3 | 2 | 2 | 3 | 2 |
| Total Suspended Solids | mg/L | 3 | 2860 | 3 | <3 | <3 | 3 |
| Turbidity | NTU | 0.1 | 37 | 2.6 | 0.49 | 0.26 | <0.1 |

Notes: mg/L = milligrams per litre; % = percent; µS/cm = microSiemens per centimetre; NTU = nephelometric units; TCU = total colour units

[1] HDS = high-density sludge

[2] PP8/HDS/$H_2O_2$ = high-density sludge removal with hydrogen peroxide oxidation

< = less than detection limit

## Table IX.8-14
## Analytical Results for Metals Measured in Untreated and Treated Mine Water used in the Mine Water Discharge Toxicity Tests

| Parameter | Units | Untreated Minewater[1] | | Untreated Supernatent[1] | | Treated (Flocculent & Filtration)[2] | | HDS[2,3] | | PP8/HDS/$H_2O_2$[2,3] | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total | Dissolved | Total | Dissolved | Total | Dissolved | Total | Dissolved | Total | Dissolved |
| Bismuth (Bi) | ug/L | 0.2 | 0.07 | 0.6 | 0.15 | < 0.03 | < 0.03 | < 0.03 | < 0.03 | < 0.03 | < 0.03 |
| Cesium (Cs) | ug/L | < 50 | 0.3 | < 50 | 0.3 | 0.4 | 0.4 | 0.3 | 0.3 | 0.1 | 0.1 |
| Lithium (Li) | ug/L | 43 | 36 | 37 | 36.2 | 39.8 | 41.1 | 36.4 | 33.5 | 23.2 | 24.4 |
| Rubidium (Rb) | ug/L | < 50 | < 50 | < 50 | < 50 | 15 | 15 | 11 | 11 | 15 | 15 |
| Selenium (Se) | ug/L | < 0.4 | < 0.4 | < 0.4 | < 0.4 | < <0.4 | < 0.4 | <0.4 | < 0.4 | < 0.4 | < 0.4 |
| Thallium (Tl) | ug/L | 8.1 | 9.1 | 6 | 6.81 | 0.04 | 0.04 | < 0.03 | < 0.03 | < 0.03 | < 0.03 |
| Tin (Sn) | ug/L | < 0.4 | < 0.2 | < 0.4 | < 0.2 | < 0.1 | < 0.1 | 1.2 | 1.3 | < 0.1 | < 0.1 |
| Titanium (Ti) | ug/L | 81.2 | 2.1 | 9.6 | 2.3 | 1.1 | 0.7 | 0.9 | 0.7 | 0.4 | 0.2 |
| Aluminum (Al) | ug/L | 1500 | < 10 | 170 | 20 | 14.2 | 2.5 | 9.4 | 6.8 | 35.9 | 14.1 |
| Arsenic (As) | mg/L | 3 | 2.2 | 3 | 2.6 | 1.51 | 1.23 | < 0.0004 | < 0.0004 | , 0.0004 | < 0.0004 |
| Boron (B) | ug/L | 139 | 125 | 141 | 130 | 128 | 132 | 118 | 109 | 58 | 51 |
| Barium (Ba) | ug/L | 105 | 77.9 | 79.6 | 81.7 | 61 | 59.4 | 21.9 | 28.5 | 59.7 | 59.0 |
| Beryllium (Be) | ug/L | < 1 | < 0.5 | < 1 | < 0.5 | < 0.2 | < 0.2 | < 0.2 | < 0.2 | < 0.2 | < 0.2 |
| Cadmium (Cd) | ug/L | < 0.2 | < 0.1 | < 0.2 | < 0.1 | < 0.05 | < 0.05 | 0.05 | 0.09 | < 0.05 | < 0.05 |
| Cobalt (Co) | ug/L | 3 | 0.7 | 1 | 0.8 | 0.7 | 0.7 | 0.8 | 1.1 | | |
| Chromium (Cr) | ug/L | 22.1 | 2.9 | 19.9 | 2 | 1.72 | 2.58 | 0.40 | 1.14 | 1.14 | 0.64 |
| Copper (Cu) | ug/L | 4 | 2.5 | 2 | 1.9 | 2.5 | 1.9 | 1.9 | 2.6 | 2.9 | 3.0 |
| Iron (Fe) | ug/L | 2600 | 5 | 255 | < 5 | 42 | 6 | 27 | 11 | 13 | 17 |
| Mercury (Hg) | ug/L | | | | | 0.02 | 0.02 | < 0.02 | 0.02 | < 0.02 | 0.02 |
| Manganese (Mn) | ug/L | 41 | 1 | 5 | 1 | 12.2 | 11.8 | 52.4 | 38.7 | 81.4 | 81.8 |
| Molybdenum (Mo) | ug/L | 12 | 12.2 | 12.1 | 12.8 | 5.7 | 5.64 | 7.04 | 5.96 | 5.94 | 6.13 |
| Nickel (Ni) | ug/L | 35.8 | 4.8 | 9 | 6.8 | 5.14 | 3.06 | 0.72 | 0.46 | < 0.06 | < 0.06 |
| Silver (Ag) | ug/L | < 0.4 | < 0.2 | < 0.4 | < 0.2 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 |
| Lead (Pb) | ug/L | 1.1 | 0.2 | 0.3 | 0.2 | 0.28 | 0.23 | 0.26 | 0.14 | 0.16 | 0.23 |
| Antimony (Sb) | ug/L | < 5 | < 0.8 | < 5 | < 0.8 | 0.4 | 0.43 | 0.15 | 0.27 | 0.28 | 0.26 |

## Table IX.8-14
## Analytical Results for Metals Measured in Untreated and Treated Mine Water used in the Mine Water Discharge Toxicity Tests (Continued)

| Parameter | Units | Untreated Minewater[1] | | Untreated Supernatent[1] | | Treated (Flocculent & Filtration)[2] | | HDS[2,3] | | PP8/HDS/$H_2O_2$[2,3] | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total | Dissolved | Total | Dissolved | Total | Dissolved | Total | Dissolved | Total | Dissolved |
| Strontium (Sr) | ug/L | 1710 | 1610 | 1730 | 1660 | 1830 | 1780 | 1240 | 1260 | 2170 | 2210 |
| Uranium (U) | ug/L | 1.2 | 1 | 1.1 | 1 | 2 | 2.2 | 0.06 | < 0.05 | < 0.05 | < 0.05 |
| Vanadium (V) | ug/L | 7.9 | 3.9 | 5.3 | 4.6 | 1.97 | 1.29 | < 1 | < 1 | < 1 | < 1 |
| Zinc (Zn) | ug/L | 15 | 8 | 10 | 9 | 18.2 | 16 | 6.2 | 13.5 | 2.8 | 10.2 |

Notes: mg/L = milligrams per litre; µg/L = micrograms per litre

[1]chemical analyses for low level metals

[2]chemical analyses for ultra-low metals

[3] HDS = high-density sludge

[4] PP8/HDS/$H_2O_2$ = high-density sludge removal with hydrogen peroxide oxidation

< = less than detection limit

As indicated in Table IX.8-13, the treatment process removes TSS but has little effect on other routine parameters. Table IX.8-14 shows the effectiveness of the treatment processes on removal of metals.

In a comparison to the results of the toxicity tests and the analytical chemistry, the primary parameters that appeared to be related to the chronic toxicity identified in the samples were ammonia and chromium. This was discussed more specifically in the impact assessment (Section 9.4).

For the purposes of water quality modelling, the *Ceriodaphnia dubia* fecundity $IC_{25}$ value assigned to the flocculent with filtration treatment process (treated) was converted to chronic Toxic Units (TUc). The TUc is calculated by dividing 100 by the $IC_{25}$ value. The resulting TUc value of 1.75 was then treated in the same fashion as substance concentrations, and predicted toxicity levels were compared with toxicity guidelines to evaluate the potential for chronic effects on aquatic organisms (*i.e.*, TUc of 1, Alberta Environmental Protection [AEP] 1995). These guidelines were originally developed by the U.S. EPA (1991) based on a large set of whole effluent toxicity data, and predicted TUc values below the guidelines indicate the absence of chronic toxicity.

This approach is dependent on a number of assumptions. The most important assumption is that it is valid to extrapolate from laboratory toxicity data to effects on native fauna in the field. Sufficient research has been carried out to show that toxicity tests are usually predictive of effects on natural aquatic communities (Environment Canada 1996). This statement is based upon a review of laboratory-to-field validation studies that compare toxicity tests results with results from field studies of fish, invertebrates and aquatic plants. Therefore, extrapolation from toxicity test results to natural populations and communities is acceptable.

## 3.0 REFERENCES

Alberta Environmental Protection (AEP). 1995. Water quality based effluent limits procedures manual. Environmental Protection. Edmonton, Alberta.

Baker, J.L., A.C, Barefoot, L.E. Beasley, L. Burns, P. Caukins, J. Clark, R.L. Feulner, J.P. Giesy, R.L. Graney, R. Griggs, H. Jacoby, D. Laskowski, A. Maciorowski, E. Mihaich, H. Nelson, R. Parrish, R.E. Siefert, K.R. Solomon, and W. van der Schalie. 1994. Final Report: Aquatic Risk Assessment and Mitigation Dialog Group, SETAC Press, Pensacola, FL, USA.

CCME (Canadian Council of Ministers of the Environment). 1999. Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment, Winnipeg, Canada.

ECOFRAM (Ecological Committee on FIFRA Risk Assessment Methods). 1999. Ecological Committee on FIFRA Risk Assessment Methods Aquatic Report. Available at http://www.epa.gov/oppefed1/ecorisk/index.htm. U.S. Environmental Protection Agency, Washington, D.C., USA.

Emans, H.J.B., E.J. van de Plassche, J.H. Canton, P.C. Okkerman, and P.M. Sparenburg. 1993. Validation of some extrapolation methods used for effect assessment. Environmental Toxicology and Chemistry. 12:2139-2154.

Environment Canada. 1996. Guidance document on the interpretation and application of data for environmental toxicology. Environmental Protection, Conservation and Protection. Ottawa, Ontario.

MacDonald, D.D., J.B. Kemper, D.E. Smorong, and D.A. Levy. Draft (2002). Guidance on the site-specific application of water quality guidelines in Canada: Procedures for deriving numerical water quality objectives. Prepared for Canadian Council of Ministers of the Environment and Environment Canada.

ODEQ (Oregon Department of Environmental Quality). 1998. Guidance for Ecological risk Assessment: Levels I, II, III, IV. Oregon Department of Environmental Quality. Waste Management and Cleanup division. Clean up policy and Program development. Portland, Oregon.

Parkhurst, B.R. , W. Warren-Hicks, R.D. Cardwell, J. Volosin, T. Etchison, J.B. Butcher, and S.M. Covington. 1996. Methodology for aquatic ecological risk assessment. RP91-AER-1. Water Environment Research Foundation, Alexandria, Va, USA.

Posthuma, L., G.W. Suter II, T.P. Traas. Species Sensitivity Distributions in Ecotoxicology. Lewis Publishers, Boca Raton, 2002 pp. 587.

Stephan, C.E., D.I. Mount, D.J. Hansen, J.H. Gentile, G.A. Chapman and W.A. Brungs. 1985. Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses. PB85-227049. National Technical Information Services, Springfield, VA.

Suter II, G. and Barnthouse, L. 1993. Chapter 2. Assessment concepts. In: Ecological Risk Assessment. ed. G.W. Suter II. Lewis Publishers, Chelsea, MI.

Suter, G.W., II, B.W. Cornoby, C.T. Hadden, R.N. Hull, M. Stack, and F.A. Zafran. 1995. An approach for balancing health and ecological risks at Hazardous waste sites. Risk Anal. 15: 221-231.

United States Environmental Protection Agency (U.S. EPA). 1985a. Ambient water quality criteria for Copper - 1984. U.S. EPA, Office of Water. EPA 440/5-84-031, January.

United States Environmental Protection Agency (U.S. EPA). 1985b. Ambient water quality criteria for Chromium - 1984. U.S. EPA, Office of Water. EPA 440/5-84-029, January.

United States Environmental Protection Agency (U.S. EPA). 1991. Methods for Aquatic Toxicity Identification Evaluations: 600/6-91/003. Phase I Toxicity Characterization Procedures.

United States Environmental Protection Agency (U.S. EPA). 1995. Federal register 60: 15366-15425. March 23. U.S. EPA, Washington, D.C., USA.

United States Environmental Protection Agency (U.S. EPA). 2001. 2001 Update of Ambient Water Quality Criteria for Cadmium. U.S. EPA, Office of Water. EPA-822-R-01-001, April.

## TABLE REFERENCES

### Copper (Cu)

Academy of Natural Sciences. 1960. The sensitivity of aquatic life to certain chemicals commonly found in industrial wastes. Philadelphia, Pennsylvania.

Adema, D.M.M. and A.M. Degroot-Van Zijl. 1972. The influence of copper to the shrimp *Callianassa australiensis*. I. Effects of individual metals. Mar. Biol. 64: 299.

Anderson, B.G. 1948. The apparent thresholds of toxicity to *Daphnia magna* for chlorides of various metals when added to Lake Erie water. Trans. Am. Fish. Soc. 78: 96.

Anderson, P.D. and P.A. Spear. 1980b. Copper pharmacokinetics in fish gills-II. Body size relationships for accumulation and tolerance. Water Res. 14: 1107.

Andrew, R.W. 1976. Toxicity relationships to copper forms in natural waters. In: R.W. Andew, *et al.* (eds.). Toxicity to Biota of Metal Forms in Natural Water. International Joint Commission, Windsor, Ontario, Canada. p. 127.

Andros, J.D. and R.R. Garton. 1980. Acute lethality of copper, cadmium, and zinc to northern squawfish. Trans. Am. Fish. Soc.109: 235.

Arthur, J.W. and E.N. Leonard. 1970. Effects of copper on *Gammarus pseudolimnaeus*, *Physa integra*, and *Campeloma* in soft water. Jour. Fish. Res. Board Can. 27: 1277.

Bailey, H.C. and D.H.W. Liu. 1980. *Lumbricalus variegatus*, a benthic oligochaete, as a bioassay organism In: J.G. Eaton, *et al.* (eds.), Aquatic Toxicology. ASTM STP 707. American Society for Testing and Materials, Philadelphia, Pennsylvania. p. 205.

Baird, D.J., I. Barber, M. Bradley, A.M.V. Soares, and P. Calow. 1991. A comparative study of genotype sensitivity to acute toxic stress using clones of *Daphnia magna* Straus. Ecotoxicol. Environ. Saf. 21(3): 257-265.

Belanger, S.E., and D.S. Cherry. 1990. Interacting effects of pH acclimation, pH, and heavy metals on acute and chronic toxicity to *Ceriodaphnia dubia* (Cladocera). J. Crustacean Biol. 10(2): 225-235.

Benoit, D.A. 1975. Chronic effects of copper on survival, growth, and reproduction of the bluegill (*Lepomis macrochirus*). Trans. Am. Fish. Soc. 104: 353.

Biesinger, K.E. Christensen, G.M. 1972. Effects of various metals on survival, growth, reproduction, and metabolism of *Daphnia magna*. J. Fish. Res Board Can 29: 1691-1700.

Birge, W.J. 1978. Aquatic toxicology of trace elements of coal and fly ash. In: J.H. Thorp and J.W. Gibbons (eds.), Energy and Environmental Stress in Aquatic Ecosystems. CONF-771114. National Technical Information Service, Springfield, Virginia. p. 219.

Black, J.A. 1974. The effect of certain organic pollutants on copper toxicity to fish *(Lebistes reticulatus*). Ph.D. Thesis. University of Michigan, Ann Arbor.

Borgmann, U. and K.M. Ralph. 1983. Complexation and toxicity of copper and the free metal bioassay technique. Water Res. 17: 1697.

Boutet, C. and C. Chaisemartin. 1973. Specific toxic properties of metallic salts in *Austropotamobius pallipes pallipes* and *Orconectes limosus*. C.R. Soc. Biol. 167: 1973.

Brungs, W.A., *et al.* 1973. Acute and long-term accumulation of copper by the brown bullhead, *Ictalurus nebulosus*. Jour. Fish. Res. Board Can. 30: 583.

Buckley, J.A. 1983. Complexation of copper in the effluent of a sewage treatment plant and an estimate of its influence on toxicity to coho salmon. Water Res. 17: 1929.

Cabejszek, I. and M. Stasiak. 1960. Studies on the influence of some metals on water biocenosis employing *Daphnia magna*. Rozniki Panst Zakl. 11: 303.

Cairns, J., Jr., and A. Scheier. 1968. A comparison of the toxicity of some common industrial waste components tested individually and combined. Prog. Fish-Cult. 30: 3.

Cairns, J., Jr., *et al.* 1978. Effects of temperature on aquatic organism sensitivity to selected chemicals. Bulletin 106. Virginia Water Resources Research Center, Blacksburg, VA, U.S.A.

Cairns, J., Jr., *et al.* 1980. Effects of a sublethal dose of copper sulphate on the colonization rate of freshwater protozoan communities. Am. Midland Natur. 104: 93.

Chakomakos, C., *et al.* 1979. The toxicity of copper to cutthroat trout (Salmo clarki) under different conditions of alkalinity, pH, and hardness. Environ. Sci. Technol. 13: 213.

Calamari, D. and R. Marchetti. 1975. The toxicity of mixtures of metals and surfactants to rainbow trout (Salmo gairdneri Rich.). Water Res. 7: 1453.

Chapman, G.A., *et al.* Manuscript. Effects of water hardness on the toxicity of metals to *Daphnia magna*. U.S. EPA, Corvallis, Oregon.

Chapman, G.A. 1975. Toxicity of copper, cadmium and zinc to Pacific Northwest salmonids. U.S. EPA, Corvallis, Oregon.

Chapman, G.A. and J.K. McCrady. 1977. Copper toxicity: a question of form. In: R.A. Tubb (ed.) Recent advances in Fish Toxicology. EPA-600/3-77-085. National Technical Information Service, Springfield, Virginia. p.132.

Chapman, G.A. 1978. Toxicities of cadmium, copper, and zinc to four juvenile stages of chinook salmon and steelhead. Trans. Am. Fish. Soc. 107: 841.

Chapman, G.A. and D.G. Stevens. 1978. Acute lethal levels of cadmium, copper, and zinc to adult male coho salmon and steelhead. Trans. Am. Fish. Soc. 107: 837.

Chapman, G.A. 1982. Letter to Charles E. Stephen. U.S. EPA, Corvallis, Oregon. December 6.

Chynoweth, D.P., *et al.* 1976. Effect of organic pollutants on copper toxicity to fish. In: R.W. Andrew, *et al.* (eds.), Toxicity to Biota of Metal Forms in Natural Water. International Joint Commission, Windsor, Ontario, Canada. p. 145.

Dave, G. 1984. Effects of copper on growth , reproduction, survival and hemoglobin in *Daphnia magna*. Comp. Biochem. Physiol. 78C: 439.

Davis, J.C. and I.G. Shand. 1978. Acute and sublethal copper sensitivity, growth and saltwater survival in young Babine Lake sockeye salmon. Technical Report No. 847. Environment Canada, West Vancouver, British Columbia.

Deshmukh, S.S. and V.B. Marathe. 1980. Size related toxicity of copper and mercury to *Lebistes reticulata* (Peter), *Labeo rohita* (Ham.) and *Cyprinus carpio* (Linn.). Indian jour. Exp. Biol.18: 421.

Diamond, J.M., D.E. Koplish, J. Mcmahon Iii, and R. Rost. 1997. Evaluation of the water-effect ratio procedure for metals in a riverine system. Environ. Toxicol. Chem. 16(3): 509-520.

Elnabarawy, M.T., *et al.* 1986. Relative sensitivity of three daphnid species to selected organic and inorganic chemicals. Environ. Toxicol. Chem. 5: 393-398.

Finlayson, B.J. and K.M. Verrue. 1982. Toxicities of copper, zinc, and cadmium mixtures to juvenile chinook salmon. Trans. Am. Fish. Soc. 111: 645.

Geckler, J.R., *et al.* 1976. Validity of laboratory tests for predicting copper toxicity in streams. EPA-600/3-76-116. National Technical Information Services, Springfield, Virginia.

Ghosh, *et al.* 1990. Toxicity of selective metals to freshwater algae, ciliated protozoa and planktonic crustaceans. Environ. Ecol. 8: 356-360.

Giles, M.A. and J.F. Klaverkamp. 1982. The acute toxicity of vanadium and copper to eyed eggs of rainbow trout (*Salmo gairdneri*). Water Res. 16: 885.

Hale, J.G. 1977. Toxicity of metal mining wastes. Bull. Environ. Contam. Toxicol. 17: 66.

Hickey, C.W., and M.L. Vickers. 1992. Comparison of the sensitivity to heavy metals and pentachlorophenol of the mayflies *Deleatidium* spp. and the cladoceran *Daphnia magna* N.Z. J. Mar. Freshwater Res. 26(1): 87-93.

Howarth, J.H. and J.B. Sprague. 1978. Copper lethality to rainbow trout in waters of various hardness and pH. Water Res. 12: 33.

Harrison, F.l., *et al.* 1984. The toxicity of copper to the adult and early life stages of the freshwater clam, *Corbicula manilensis*. Arch. Environ. Contam. Toxicol. 13: 85.

Horning, W.B. and T.W. Neiheisel. 1979. Chronic effects of copper on the bluntnose minnow, *Pimephales notatus* (Rafinesque). Arch. Environ. Contam. Toxicol. 8: 545.

Hinton, M.J. and Eversole. 1979. Toxicity of ten chemicas commonly used in aquaculture to the black eel stage of the American eel. Prioc. World Maricul. Soc. 10: 554.

Hubschman, J.H. 1967. Effects of copper on the crayfish *Orconectes rusticus* (Girard): I. Acute toxicity. Crustaceana 12: 33.

Hughes, J.S. 1973. Acute toxicity of thirty chemicals to striped bass (*Morone saxatilis*). Presented at the Western Association of State Game and Fish Commissioners, Salt Lake City, Utah. July.

Inglis, A. and E.L. Davis. 1972. Effects of water hardness on the toxicity of several organic and inorganic herbicides to fish. Technical Paper No. 67. U.S. Fish and Wildlife Service, Washington, D.C.

Joshi, A.G. and M.S. Rege. 1980. Acute toxicity of some pesticides and a few inorganic salts to the nosquitofish *Gambusi affinis* (Baird and Girard). Indian Jour. Exp. Biol. 18: .

Keller A.E., S.G. Zam. 1991. The acute toxicity of selected metals to the freshwater mussel, *Anodonata imbecilis*. Environ Toxicol Chem 10: 539-546.

Khangarot, B.S. 1981. Chelating agent EDTA decreases the toxicity of copper to fish. Current Sci. 50: 246.

Khangarot, B.S., *et al.* 1981b. Studies on the acute toxicity of copper on selected freshwater organisms. Sci. Cult. 47: 429.

Khangarot, B.S., *et al.* 1983. "Man and the Bioshpere" – Studies on Sikkim Himalayas. Part1: acute toxicity of copper and zinc to common carp *Cyprinus carpio* (Linn.) in soft water. Acta Hydrochim. Hydrobiol. 11:667.

Khangarot, B.S., and P.K. Ray. 1989. Investigation of correlation between physicochemical properties of metals and their toxicity to the water flea *Daphnia magna* Straus. Ecotoxicol. Environ. Saf. 18(2): 109-120.

Kosalwat, P. and Knight, A.W. 1987. Acute toxicity of aqueous and substrate-bound copper to the midge, *Chironomus decorus*. Arch. Environ. Contam. Toxicol 16: 275-282.

Lazorchak, J.M., and W.T. Waller. 1993. The relationship of total copper 48-H LC50s to *Daphnia magna* dry weight. Environ. Toxicol. Chem. 12: 903-911.

Lewis, MA. 1983. Effects of loading density on the acute toxicities of surfactants, copper, and phenol to Daphnia magna Straus. Arch. Environ. Contam. Toxicol. 12: 51.

Lind, D., *et al.* Manuscript. Regional copper-nickel study: aquatic toxicology study.

Lorz, H.W. and B.P. McPherson. 1976. Effects of copper or zinc in fresh water on the adaptation to sea water and ATPase activity, and the effects of copper on migratory disposition of coho salmon (*Oncorhynchus kisutch*). Jour. Fish. Res. Board Can. 33: 2023.

Martin, T.R., and Holdich, D.M. 1986. The acute lethal toxicity of heavy metals to peracarid crustaceans (with particular reference to fresh water asellids and gammarids). Water Res. 20: 1137-1147.

McKim, J.M. and D.A. Benoit. 1971. Effects of long-term exposures to copper on survival, growth, and reproduction of brook trout (Salvelinus fontinalis). Jour. Fish Res. Board Can. 28:665.

McKim, J.M., *et al.* 1978. Metal toxicity to embryos and larvae of eight species of freshwater fish. – II. Copper. Bull Environ. Contam. Toxicol. 19: 608.

Mount, D.I. 1968. Chronic toxicity of copper to fathead minnows (*Pimephales promelas* Rafinesque). Water Res. 2: 215.

Mount, D.I. and C.E. Stephan. 1969. Chronic toxicity of copper to the fathead minnow (*Pimephales promelas*) in soft water. Jour. Fish. Res. Board Can. 26: 2449.

Mount, D.I. and T.J. Norberg. 1984. A seven-day life cycle cladocerm toxicity test. Environ. Toxicol. Chem. 3: 425.

Nebeker, A.V. and A.R. Gaufin. 1964. Bioassays to determine pesticide toxicity to the amphipod crustacean, *Gammarus lacustris.* Proc. Utah Acad. Sci. 41: 64.

Nebeker, A.V., *et al.* 1984a. Relative sensitivity of Chironomus tentans life stages to copper. Environ. Toxicol. Chem. 3: 151.

Nebeker, A.V., M.A. Cairns, S.T. Onjukka, and R.H. Titus. 1986. Effect of age on sensitivity of *Daphnia magna* to cadmium, copper and cyanazine. Environ. Toxicol. Chem. 5(6): 527-530.

O'Hara, J. 1971. Alterations in oxygen consumption by bluegills exposed to sublethal treatment with copper. Water Res. 5: 321.

Oikari, A., J. Kukkonen, and V. Virtanen. 1992. Acute toxicity of chemicals to *Daphnia magna* in humic waters. Sci. Total Environ. 117/118: 367-377.

Oris, J.T., R.W. Winner, and M.V. Moore. 1991. A four-day survival and reproduction toxicity test for *Ceriodaphnia dubia.* Environ. Toxicol. Chem. 10(2): 217-224.

Pardue, W.J. and T.S. Wood. 1980. Baseline toxicity data for the freshwater bryozoa exposed to copper, cadmium, chromium, and zinc. Jour. Tennessee Acad. Sci. 55: 27.

Paulson, P.C., *et al.* 1983. Relationship of alkaline stress and acute copper toxicity in the snail *Goniobasis livescens* (Menke). Bull Environ. Contam. Toxicol. 31: 719.

Pickering, Q., *et al.* 1977. Effect of exposure time and copper concentration on reproduction of the fathead minnow (*Pimephales promelas*). Water Res. 11: 1079.

Pickering, Q.H. and C. Henderson. 1966. The acute toxicity of some heavy metals to different species of warmwater fishes. Air Water Pollut. Int. Jour. 10: 453.

Qureshi, S.A. and A.B. Saksena. 1980. The acute toxicity of some heavy metals *to Tilapia mossambica* (Peters). Aqua 1: 19.

Rehwoldt, R., *et al.* 1971. Acute toxicity of copper, nickel and zinc ions to some Hudson River fish species. Bull Environ. Contam. Toxicol. 6: 445.

Rehwoldt, R., *et al.* 1972. The effect of increased temperature upon the acute toxicity of some heavy metal ions. Bull Environ. Contam. Toxicol. 8: 91.

Rehwoldt, R., *et al.* 1973. The acute toxicity of some heavy metal ions toward benthic organisms. Bull. Environ. Contam. Toxicol. 10: 291.

Rice, D.W., Jr., and F.L. Harrison. 1983. The sensitivity of adult, embryonic, and larval crayfish *Procambaris clarkii* to copper. UCRL-53048. National Technical Information Service, Springfield, Virginia.

Rodgers, J.H., *et al.* 1980. Comparison of heavy metal interactions in acute and artificial stream bioassay techniques for the Asiatic clam (*Corbicula fluminen*). In: J.G. Eaton *et al.* (eds.), Aquatic toxicology. ASTM STP 707. American Society for Testing and Materials, Philadelphia, Pennsylvania. p. 266.

Sauter , S., *et al.* 1976. Effects of exposure to heavy metals on selected freshwater fish. Toxicity of copper, cadmium, chromium and lead to eggs and fry of seven fish species. EPA-600/3-76-105. National Technical Information Service, Springfield, Virginia.

Seim, W.K., *et al.* 1984. Growth and survival of developing steelhead *trout (Salmo gairdneri*) continuously or intermittently exposed to copper. Can. Jour. Fish. Aquat. Sci. 41: 433.

Skidmore, J.F., and Firth, I.C. 1983. Acute sensitivity of selected Australian freshwater animals to copper and zinc. Technical paper 81. Australian Water Resources Council, Canberra, pp. 24-67.

Spear, P. 1977. Copper accumulation kinetics and lethal tolerance in relation to fish size. M.S. Thesis. Concordia University, Montreal Canada.

Sprague, J.B. 1964. Lethal concentrations of copper and zinc for young Atlantic salmon. Jour. Fish. Res. Board can. 21:17.

Sprague, J.B. and B.A. Ramsay. 1965. Lethal levels of mixed copper-zinc solutions for juvenile salmon. Jour. Fish. Res. Board Can. 22: 425.

Stephenson, R.R. 1983. Effects of water hardness. Water temperature, and size of the test organism on the susceptibility of the freshwater shrimp, *Gammarus pulex* (L.) to toxicants. Bull. Environ. Contam. Toxicol. 31: 459.

Tarzwell, C.M. and C. Henderson. 1960. Toxicity of less common metals to fishes. Ind. Wastes 5: 12.

Taylor, E.J., *et al.* 1991. Toxicity of four common pollutants to the freshwater macroinvertebrates *Chironomus riparius* Meigen (Insecta: Diptera) and *Gammarus pulex* (L.) (Crustacea: Amphipoda). Arch. Environ. Contam. Toxicol. 21: 371:376.

Thompson, K.W. 1980. Acute toxicity of zinc and copper singly and in combination to the bluegill (*Lepomis macrochirus*). Bull. Environ. Contam. Toxicol. 25: 122.

Tsai, C. and J.A. McKee. 1978. The toxicity to goldfish of mixtures of chloramines, LAS and copper. PB 280554. National Technical Information Service, Springfield, Virginia.

Tsai, C. and J.A. McKee. 1980. Acute toxicity to goldfish of mixtures of chloramines, copper, and linear alkylate sulfonate. Trans Am. Fish. Soc. 109:132.

Vincent, M., *et al.* 1986. Action comparee dela toxcite de chlorures metalliques et d'un molluscicide organique de synthese, la N-trityl-morpholine, sur duex amphipose dulcaquicoles *Gammarus pulex* et *Echinogammarus berilloni*. Anales de Recherches Veterinaires 17:441-446.

Warnick, S.L. and H.L. Bell. 1969. The acute toxicity of some heavy metals to different species of aquatic insects. Jour. Water Pollut. Control Fed. 41: 280.

Welborn, T.L., Jr. 1969. The toxicity of nine therapeutic and herbicidal compounds to striped bass. Prog. Fish-Cult. 31: 27.

Wilson, R.C.H. 1972. Prediction of copper toxicity in receiving waters. Jour. Fish. Res. Board Can. 29: 1500.

Winner, R.W. and M. P. Farrel. 1976. Acute and chronic toxicity of copper to four species of *Daphnia*. Jour. Fish. Res. Board Can. 33: 1685.

Wurtz, C.B. and C.H. Bridges. 1961. Preliminary results from macroinvertebrate bioassays. Proc. Pennsylvania Acad. Sci. 35: 51.

**Cadmium (Cd)**

Andros, J.D., and R.R. Garton. 1980. Acute Lethality of Copper, Cadmium, and Zinc to Northern Squawfish. Trans. Am. Fish. Soc.; 109(2): 235-238.

Attar, E.N., and E.J. Maly. 1982. Acute Toxicity of Cadmium, Zinc, and Cadmium-Zinc Mixtures to Daphnia magna. Arch. Environ. Contam. Toxicol.; 11(3): 291-296.

Baird, D.J., Barber, I., Bradley, M., Soares, A.M.V., and P. Calow. 1991. A Comparative Study of Genotype Sensitivity to Acute Toxic Stress Using Clones of Daphnia magna Straus. Ecotoxicol. Environ. Saf.; 21(3): 257-265.

Benoit, D.A., Leonard, E.N., Christensen, G.M., and J.T. Fiandt. 1976. Toxic Effects of Cadmium on Three Generations of Brook Trout (Salvelinus fontinalis). Trans. Am. Fish. Soc.; 105(4): 550-560.

Bertram, P.E., and B.A. Hart. 1979. Longevity and Reproduction of Daphnia pulex (Degeer) Exposed to Cadmium-Contaminated Food or Water. Environ. Pollut.; 19(4): 295-306.

Biesinger, K.E., and G.M. Christensen. 1972. Effects of Various Metals on Survival, Growth, Reproduction and Metabolism of Daphnia magna. J. Fish. Res. Board Can.; 29: 1691-1700.

Birge, W.J., Benson, W.H., and J.A. Black. 1983. The Induction of Tolerance to Heavy Metals in Natural and Laboratory Populations of Fish. Res.Rep.No.141, Water Resour. Res. Inst., University of Kentucky, Lexington, KY: 26

Bishop, W.E., and A.W. McIntosh. 1981. Acute Lethality and Effects of Sublethal Cadmium Exposure on Ventilation Frequency and Cough Rate of Bluegill (Lepomis macrochirus). Arch. Environ. Contam. Toxicol.; 10: 519-530.

Bitton, G., Rhodes, K., and B. Koopman. 1996. Ceriofast: An Acute Toxicity Test Based on Ceriodaphnia dubia Feeding Behavior. Environ. Toxicol. Chem.; 15(2): 123-125.

Bodar, C.W.M., Van Leeuwen, C.J., Voogt, P.A., and D.I. Zandee. 1988. Effect of Cadmium on the Reproduction Strategy of Daphnia magna. Aquat. Toxicol.; 12(4): 301-310.

Bosnak, A.D., and E.L. Morgan. 1981. Acute Toxicity of Cadmium, Zinc, and Total Residual Chlorine to Epigean and Hypogean Isopods (Asellidae). Natl. Speleological Soc. Bull.; 43: 12-18.

Brata, C., D.J. Baird, and S.J. Markich. 1998. Influence of Genetic and Environmental Factors on the Tolerance of Daphnia magna Straus to Essential and Non-Essential Metals. Aquat. Toxicol.; 42(2): 115-137.

Brown, A.F., and D. Pascoe. 1988. Studies on the Acute Toxicity of Pollutants to Freshwater Macroinvertebrates. 5. The Acute toxicity of Cadmium to Twelve Species of Predatory. Arch. Hydrobiol.; 114(2): 311-319.

Brown, V., Shurben, D., Miller, W., and M. Crane. 1994. Cadmium Toxicity to Rainbow Trout Oncorhynchus mykiss Walbaum and Brown Trout Salmo trutta L. over Extended Exposure Periods. Ecotoxicol. Environ. Saf.; 29: 38-46.

Buhl, K.J., and S.J. Hamilton. 1991. Relative Sensitivity of Early Life Stages of Arctic Grayling, Coho Salmon, and Rainbow Trout to Nine Inorganics. Ecotoxicol.Environ.Saf.; 22: 184-197.

Buhl, K.J. 1997. Relative Sensitivity of Three Endangered Fishes, Colorado Squawfish, Bonytail, and Razorback Sucker, to Selected Metal Pollutants. Ecotoxicol. Environ. Saf.; 37: 186-192.

Canton, J.H., and W. Slooff. 1982. Toxicity and Accumulation Studies of Cadmium (Cd2+) with Freshwater Organisms of Different Trophic Levels. Ecotoxicol. Environ. Saf.; 6(1): 113-128.

Carrier, R., and T.L. Beitinger. 1988a. Reduction in Thermal Tolerance of Notropis lutrensis and Pimephales promelas Exposed to Cadmium. Water Res.; 22(4): 511-515.

Carrier, R., and T.L. Beitinger. 1988b. Resistance of Temperature Tolerance Ability of Green Sunfish to Cadmium Exposure. Bull. Environ. Contam. Toxicol.; 40(4): 475-480

Carroll, J.J., Ellis, S.J., and W.S. Oliver. 1979. Influences of Hardness Constituents on the Acute Toxicity of Cadmium to Brook Trout (Salvelinus fontinalis). Bull. Environ. Contam. Toxicol.; 22(4/5): 575-581

Chapman, G.A. 1975. Toxicity of Copper, Cadmium, and Zinc to Pacific Northwest Salmonids. Interim Report, Task 002 ROAP 10CAR, U.S.EPA, Corvallis, OR: 27 p.(Letter to C.E. Stephan, U.S. EPA, Duluth, MN:5 p.) (1982)

Chapman, G.A. 1978. Toxicities of Cadmium, Copper, and Zinc to Four Juvenile Stages of Chinook Salmon and Steelheads. Trans. Am. Fish. Soc.; 107(6): 841-847

Chapman, G.A., Ota, S., and F. Recht. 1980. Effects of Water Hardness on the Toxicity of Metals to Daphnia magna. U.S.EPA, Corvallis, OR:17 p.

Chapman, P.M., Farrell, M.A., and R.O. Brinkhurst. 1982. Relative Tolerances of Selected Aquatic Oligochaetes to Individual Pollutants and Environmental Factors. Aquat. Toxicol.; 2(1): 47-67.

Chapman, P.M., Farrell, M.A., and R.O. Brinkhurst. 1982. Relative Tolerances of Selected Aquatic Oligochaetes to Combinations of Pollutants and Environmental Factors. Aquat. Toxicol.; 2(1): 69-78.

Chapman, P.M., Farrell, M.A., and R.O. Brinkhurst. 1982. Effects of Species Interactions on the Survival and Respiration of Limnodrilus hoffmeisteri and Tubifex tubifex (Oligochaeta, Tubificidae) Exposed to. Water Res.; 16(9): 1405-1408.

Crisinel, A., Delaunay, L., Rossel, D., Tarradellas, J. Meyer, H., Saiah, H., Vogel, P., Delisle, C., and C. Blaise. 1994. Cyst-Based Ecotoxicological Tests Using Anostracans: Comparison of Two Species of Streptocephalus. Environ. Toxicol. Water Qual.; 9(4): 317-326.

Cusimano, R.F., Brakke, D.F., and G.A. Chapman. 1986. Effects of pH on the Toxicities of Cadmium, Copper, and Zinc to Steelhead Trout (Salmo gairdneri). Can. J. Fish. Aquat. Sci.; 43(8): 1497-1503.

Davies, P. 1976. Use of Dialysis Tubing in Defining the Toxic Fractions of Heavy Metals in Natural Waters. *In:* R.W.Andrew, P.V.Hodson, and D.E.Konasewich (Eds.) Toxicity to Biota of Metal Forms in Nat.Water, Int.Joint Comm., Windsor, Canada: 110-117.

Diamond, J.M., Koplish, D.E., Mcmahon J. III, and R. Rost. 1997. Evaluation of the Water-Effect Ratio Procedure for Metals in a Riverine System. Environ. Toxicol. Chem.; 16(3): 509-520.

Duncan, D.A., and J.F. Klaverkamp. 1983. Tolerance and Resistance to Cadmium in White Suckers (Catostomus commersoni) Previously Exposed to Cadmium, Mercury, Zinc, or Selenium. Can. J. Fish. Aquat. Sci.; 40(2): 128-138.

Eaton, J.G., McKim, J.M., and G.W. Holcombe. 1978. Metal Toxicity to Embryos and Larvae of Seven Freshwater Fish Species - 1. Cadmium. Bull. Environ. Contam. Toxicol.; 19: 95-103.

Eaton, J.G. 1980. Memo to C.E.Stephan, U.S. EPA. August 5,1980. "Chronic Cadmiun Toxicity to the Bluegill (Lepomis macrochirus Rafinesque). Memo to C.E. Stephan, U.S. EPA, Duluth, MN :1p.

Elnabarawy, M.T., Welter, A.N., and R.R. Robideau. 1986. Relative Sensitivity of Three Daphnid Species to Selected Organic and Inorganic Chemicals. Environ. Toxicol. Chem.; 5(4): 393-398.

Finlayson, B.J., and K.M. Verrue. 1982. Toxicities of Copper, Zinc, and Cadmium Mixtures to Juvenile Chinook Salmon. Trans. Am. Fish. Soc.; 111(5): 645-650.

Gaikwad, S.A. 1989. Effects of Mixture and Three Individual Heavy Metals on Susceptibility of Three Fresh Water Fishes. Pollut. Res.; 8(1): 33-35.

Gisey, J.P. Jr., Leversee, G.J., and D.R. Williams. 1977. Effects of Naturally Occurring Organic Fractions of Cadmium Toxicity to Simocephalus serrulautus (Daphnidae) and Gambusia affinis (Poeciliidae). Water Res.; 11(11): 1013-1020.

Ghosh, T.K., Kotangale, J.P., and K.P. Krishnamoorthi. 1990. Toxicity of Selective Metals to Freshwater Algae, Ciliated Protozoa and Planktonic Crustaceans. Environ. Ecol.; 8(1 B): 356-360.

Guilhermino, L., Lopes, M.C., Carvalho, A.P., and A.M.V. Soares. 1996. Inhibition of Acetylcholinesterase Activity as Effect Criterion in Acute Tests with Juvenile Daphnia magna. Chemosphere; 32(4): 727-738.

Hall, W.S., Paulson, R.L., Hall, L.W. Jr., and D.T. Burton. 1986. Acute Toxicity of Cadmium and Sodium Pentachlorophenate to Daphnids and Fish. Bull. Environ. Contam. Toxicol.; 37(2): 308-316.

Ham, L., Quinn, R., and D. Pascoe. 1995. Effects of Cadmium on the Predator-Prey Interaction Between the Turbellarian Dendrocoelum lacteum (Muller, 1774) and the Isopod Crustacean Asellus. Arch. Environ. Contam.Toxicol. 29(3): 358-365.

Hamilton, S.J., and K.J. Buhl. 1990. Safety Assessment of Selected Inorganic Elements to Fry of Chinook Salmon (Oncorhynchus tshawytscha). Ecotoxicol. Environ. Saf.; 20(3): 307-324.

Hatakeyama, S., and M. Yasuno. 1981. Effects of Cadmium on the Periodicity of Parturition and Brood Size of Moina macrocopa (Cladocera). Environ. Pollut. Ser. A. Ecol. Biol.; 26: 111-120.

Holcombe, G.W., Phipps, G.L., and J.T. Fiandt. 1983. Toxicity of Selected Priority Pollutants to Various Aquatic Organisms. Ecotoxicol. Environ. Saf.; 7(4): 400-409.

Holcombe, G.W., Phipps, G.L., and J.W. Marier. 1984. Methods for Conducting Snail (Aplexa hypnorum) Embryo Through Adult Exposures: Effects of Cadmium and Reduced pH Levels. Arch. Environ. Contam. Toxicol.; 13(5): 627-634.

Hughes, J.S. 1973. Acute Toxicity of Thirty Chemicals to Striped Bass (Morone saxatilis). La. Dep. Wildl. Fish. 318-343-2417:15 p. (Used 963 As Reference).

Ingersoll, C.G., and N. Kemble. 2000. Unpublished. Methods Development for Long-term Sediment Toxicity Tests wit the Amphipod Hyalella azteca and the Midge Chironomus tentans.

Jop, K.M., Askew, A.M., and R.B. Foster. 1995. Development of a Water-effect Ration for Copper, Cadmium and Lead for the Great Works River in Maine Using Ceriodaphnia dubia and Salvelinus fontinalis. Bull. Environ. Contam. Toxicol.; 54: 29-33.

Jude, D.J. 1973. Sublethal Effects of Ammonia and Cadmium on Growth of Green Sunfish, (Lepomis cyanellus). Ph.D.Thesis, Mich. Dep. Fish. Wildl., Michigan State University, East Lansing, MI:193.

Keller, A.E., and S.G. Zam. 1991. The Acute Toxicity of Selected Metals to the Freshwater Mussel, Anodonta imbecilis. Environ. Toxicol. Chem.; 10(4): 539-546.

Keller, A.E. Unpublished.

Lee, S. III, Na, E.J., Cho, Y.O., Coopman, B., and G. Bitton. 1997. Short-term Toxicity Test Based on Algal Uptake by Ceriodaphnia dubia. Water Environment Research; 69(7): 1207-1210.

Lorz, H.W., Williams, R.H., and C.A. Fustish. 1978. Effects of Several Metals on Smolting of Coho Salmon. EPA-600/3-78-090, U.S.EPA, Environ. Res. Lab, Corvallis, OR:84

Martin, T.R., and D.M. Holdich. 1986. The Acute Lethal Toxicity of Heavy Metals to Peracarid Crustaceans (with Particular Reference to Fresh-Water Asellids and Gammarids). Water Res.; 20(9): 1137-1147.

McCarty, L.S., Henry, J.A.C., and A.H. Houston. 1978. Toxicity of Cadmium to Goldfish Carassius auratus in Hard and Soft Water Reference Source: J. Fish. Res. Board Can.; 35(1): 35-42.

Mirenda, R.J. 1986. Toxicity and Accumulation of Cadmium in the Crayfish, Orconectes virilis (Hagen) Arch. Environ. Contam. Toxicol.; 15(4): 401-407.

Naqvi, S.M., and R.D. Howell. 1993. Toxicity of Cadmium and Lead to Juvenile Red Swamp Crayfish, Procambarus clarkii, and Effects on Fecundity of Adults. Bull. Environ. Contam. Toxicol.; 51: 303-308.

Nebeker, A.V., Schuytema, G.S., and S.L. Ott. 1995. Effects of Cadmium on Growth and Bioaccumulation in the Northwestern Salamander Ambystoma gracile. Arch. Environ. Contam. Toxicol.; 29(4): 492-499.

Niederlehner, B.R., Buikema, A.L., Jr., Pittinger, C.A., J. Cairns, and Jr. 1984. Effects of Cadmium on the Population Growth of a Benthic Invertebrate Aeolosoma headleyi (Oligochaeta). Environ. Toxicol. Chem.; 3(2): 255-262.

Palawski, D., Hunn, J.B., and F.J. Dwyer. 1985. Sensitivity of Young Striped Bass to Organic and Inorganic Contaminants in Fresh and Saline Waters. Trans. Am. Fish. Soc.; 114: 748-753.

Pardue, W.J., and T.S. Wood. 1980. Baseline Toxicity Data for Freshwater Bryozoa Exposed to Copper, Cadmium, Chromium, and Zinc. J. Tenn. Acad. Sci.; 55(1): 27-31

Pascoe, D., and P. Cram. 1977. The Effect of Parasitism on Toxicity of Cadmium to the Three-Spined Stickleback, (Gasterosteus aculeatus) L. J. Fish Biol.; 10(5): 467-472.

Pascoe, D., and D.L. Mattey. 1977. Studies on the Toxicity of Cadmium to the Three-Spined Stickleback (Gasterosteus aculeatus) L. J. Fish Biol.; 11(2): 207-215.

Pascoe, D., Brown, A.F., Evans, B.M.J., and C. McKavanagh. 1990. Effects and Fate of Cadmium during Toxicity Tests with Chironomus riparius - the Influence of Food and Artificial Sediment. Arch. Environ. Contam. Toxicol.; 19(6): 872-877.

Pickering, Q.H., and M.H. Gast. 1972. Acute and Chronic Toxicity of Cadmium to the Fathead Minnow (Pimephales promelas). J. Fish. Res. Board Can.; 29(8): 1099-1106.

Pickering, Q.H., and C. Henderson. 1966. The Acute Toxicity of some Heavy Metals to Different Species of Warm Water Fishes. Air, Water, Pollut. Int. Jour; 10: 453.

Phipps, G.L., and G.W. Holcombe. 1985. A Method for Aquatic Multiple Species Toxicant Testing: Acute Toxicity of 10 Chemicals to 5 Vertebrates and 2 Invertebrates. Environ. Pollut. Ser. A Ecol. Biol.; 38(2): 141-157 (Author Communication Used).

Rifici, L.M., Cherry, D.S., Farris, J.L., and J. Cairns Jr. 1996. Acute and Subchronic Toxicity of Methylene Blue to Larval Fathead Minnows (Pimephales promelas): Implications for Aquatic Toxicity Testing. Environ. Toxicol. Chem.; 15(8): 1304-1308.

Rombough, P.J., and E.T. Garside. 1982. Cadmium Toxicity and Accumulation in Eggs and Alevins of Atlantic Salmon Salmo salar. Can. J. Zool.; 60(8): 2006-2014.

Reynoldson, T.B., Rodriguez, P., and M.M. Madrid. 1996. A Comparison of Reproduction, Growth and Acute Toxicity in Two Populations of Tubifex tubifex (Muller, 1774) from the North American Great Lakes. Hydrobiologia; 334(1-3): 199-206.

Roux, D.J., Kempster, P.L., Truter, E., and L. Van der Merwe. 1993. Effect of Cadmium and Copper on Survival and Reproduction of Daphnia pulex. Water S.A.; 19(4): 269-274.

Sauter, S., Buxton, K.S., Macek, K.J., and S.R. Petrocelli. 1976. Effects of Exposure to Heavy Metals on Selected Freshwater Fish: Toxicity of Copper, Cadmium, Chromium and Lead to Eggs and Fry of Seven Fish. EPA-600/3-76-105, Environ. Res. Lab., U.S. EPA, Duluth, MN: 74.

Schubauer-Berigan, M.K., Dierkes, J.R., Monson, P.D., and G.T. Ankley. 1993. pH-Dependent Toxicity of Cd, Cu, Ni, Pb and Zn to Ceriodaphnia dubia, Pimephales promelas, Hyalella azteca and Lumbriculus variegatus. Environ. Toxicol. Chem.; 12:1261-1266.

Sherman, R.E., Gloss, S.P., and L.W. Lion. 1987. A Comparison of Toxicity Tests Conducted in the Laboratory and in Experimental Ponds Using Cadmium and the Fathead Minnow (Pimephales promelas). Water Res.; 21(3): 317-323.

Spehar, R.L. 1976a. Cadmium and Zinc Toxicity to Flagfish, Jordanella floridae. J. Fish. Res. Board Can.; 33(9): 1939-1945

Spehar, R.L. 1976b. Cadmium and Zinc Toxicity to Jordanella floridae. Ecol. Res. Ser., EPA-600/3-76-096, Environ.Res.Lab., U.S. EPA, Duluth, MN:34; M.S.Thesis, University of Minnesota, Minneapolis, MN:67 p.(1974).

Spehar, R.L. 1982. Memorandum to J.G. Eaton. U.S. EPA. Duluth, Minnesota. February 24.

Spehar, R.L., and J.T. Fiandt. 1986. Acute and Chronic Effects of Water Quality Criteria-Based Metal Mixtures on Three Aquatic Species. Environ. Toxicol. Chem.; 5(10): 917-931.

Spehar, R.L., and A.R. Carlson. 1984a. Derivation of Site-Specific Water Quality Criteria for Cadmium and the St. Louis River Basin, Duluth, Minnesota. PB84-153196. National Technical Information Services. Springfield, Virginia.

Spehar, R.L., and A.R. Carlson. 1984b. Derivation of Site-Specific Water Quality Criteria for Cadmium and the St. Louis River Basin, Duluth, Minnesota. Environ. Toxicol. Chem.; 3(4): 651-665 (Feb.24, 1982 Memo to J.G.Eaton, U.S. EPA, Duluth, MN) : 651-622.

Stackhouse, R.A., and W.H. Benson. 1988. The Influence of Humic Acid on the Toxicity and Bioavailability of Selected Trace Metals. Aquat. Toxicol.; 13(2): 99-108.

Stratus Consulting. 1999. Prepared by: Hansen, J.A., J. Lipton, and P.G. Welsh . Subchronic Toxicity of Cadmium to Bull Trout. Presented at the 21st Annual Meeting of Society of Environmental Toxicology and Chemistry, Nashville, TN. November 12-16, 2000.

Stuhlbacher, A., Bradley, M.C., Naylor, C., and P. Calow. 1992. Induction of Cadmium Tolerance in Two Clones of Dapnia magna Straus. Comp. Biochem. Physiol.; 101C(3): 571-577.

Sunderman, F.W., Jr., Plowman, M.C. and S.M. Hopfer. 1991. Embryotoxicity and Teratogenecity of Cadmium Chloride in Xenopus laevis, Assayed by the FETAX Procedures. Annals of Clinical and Laboratory Science; 21(6); 381-391.

Suresh, A., Sivaramakrishna, B., and K. Radhakrishnaiah. 1993. Patterns of Cadmium Accumulation in the Organs of Fry and Fingerlings of Freshwater Fish Cyprinus carpio Following Cadmium Exposure. Chemosphere; 26(5): 945-953.

Suresh, A., Sivaramakrishna, B., and K. Radhakrishnaiah. 1993. Effect of Lethal and Sublethal Concentrations of Cadmium on Energetics in the Gills of Fry and Fingerlings of Cyprinus carpio. Bull. Environ. Contam. Toxicol.; 51(6):920-926

Warnick, S.L., and H.L. Bell. 1969. The Acute Toxicity of Some Heavy Metals to Different Species of Aquatic Insects. J. Water Pollut. Control Fed.; 41(2): 280-284.

Wier, C.F., and W.M. Walter. 1976. Toxicity of Cadmium in the Freshwater Snail, Physa gyrina Say. J. Environ. Qual.; 5(4): 359-362.

Williams, K.A., Green, D.W.J., and D. Pascoe. 1985. Studies on the Acute Toxicity of Pollutants to Freshwater Macroinvertebrates. 1. Cadmium. Arch. Hydrobiol.; 102(4): 461-471.

**Hexavalent Chromium (Cr VI)**

Abbasi, S.A., P.C. Nipaney, and R. Soni. 1988. Studies on environmental management of mercury (II), chromium (VI) and zinc (II) with respect to the impact on some arthropods and protozoans. Int. J. Environ. Stud. 32: 181-187.

Academy of Natural Sciences. 1960. The sensitivity of aquatic life to certain chemicals commonly found in industrial wastes. Philadelphia, Pennsylvania.

Adelman, I.R. and L.L. Smith, Jr. 1976. Standard test fish development. Part 1. Fathead minnows (*Pimephales promelas*) and goldfish (*Carassius auratus*) as standard fish in bioassays and their reaction to potential reference toxicants. EPA-600-3-76-061a. National Technical Information Service, Springfield, Virginia.

Al Akel, A.S., and M.J.K. Shamsi. 1996. Hexavalent chromium: toxicity and impact on carbohydrate metabolism and haematological parameters of carp (*Cyprinus carpio L.*) from Saudi Arabia. Aquat. Sci. 58(1): 24-30.

Batac-Catalan, Z. and D.S. White. 1983. Effect of chromium on larval chironomidae as determined by the optical-fibre light-interruption biomonitoring system. *In*: W.E. Bishop, *et al.* (eds.), Aquatic Toxicology and Hazard Assessment: Sixth Symposium. ASTM STP 802. American society for Testing and Materials, Philadelphia, Pennsylvania. P. 469.

Benoit, D.A. 1976. Toxic effects of hexavalent chromium on brook trout (*Salvelinus fontinalis*) and rainbow trout (*Salmo gairdneri*). Water Res. 10: 497.

Cairns, J., Jr., and A. Scheier. 1968. A comparison of the toxicity of some common industrial waste components tested individually and combined. Prog. Fish-Cult. 30: 3.

Cairns, J., Jr., *et al.* 1978. Effects of temperature on aquatic organism sensitivity to selected chemicals. Bulletin 106. Virginia Water Resources Research Center, Blacksburg, Virginia.

Cairns, J., Jr., *et al.* 1981. Effects of fluctuating sublethal applications of heavy metal solutions upon the gill ventilatory response of bluegills (*Lepomis macrochirus*). EPA-600/3-81-003. National Technical Information Service, Springfield, Virginia.

Call, D.J., *et al.* 1981. Aquatic pollutant hazard assessments and development of hazard prediction technology by quantitative structure-activity relationships. Second Quarterly Report to EPA. Center for Lake Superior Environmental Studies, University of Wisconsin-Superior, Superior, Wisconsin.

Dowden, B.F. and H.J. Bennett. 1965. Toxicity of selected chemicals to certain animals. Jour. Water Polut. Control Fed. 37: 1308.

Hickey, C. 1989. Sensitivity of four New Zealand cladoceran species and *Daphnia magna* to aquatic toxicants. N.Z. J. Mar. Freshwater Res. 23: 131-137.

Hughes, J.S. 1973. Acute toxicity of thirty chemicals to striped bass (*Morone saxatilis*). Presented at the Western Association of State Game and Fish Commisioners, Salt Lake City, Utah. July.

Mount, D.I. 1982. Memorandum to Charles E. Stephan. U.S. EPA, Duluth, Minnesota. June 7.

Mount, D.I. and T.J. Norberg. 1984. A seven-day life-cycle cladoceran toxicity test. Environ. Toxicol. Chem. 3: 425.

Pardue, W.J. and T.S. Wood. 1980. Baseline toxicity data for freshwater Bryozoa exposed to copper, cadmium, chromium, and zinc. Jour. Tennessee Acad. Sci. 55: 27.

Patrick, R., *et al.* 1968. The relative sensitivity of diatoms, snails, and fish to twenty common constituents of industrial waste. Prog. Fish-Cult. 30:00137.

Pickering, Q.H. 1980. Chronic toxicity of hexavalent chromium to the fathead minnow (*Pimephales promelas*). Arch. Environ. Contam. Toxicol. 9: 405.

Pickering, G.H. and C. Henderson. 1966. The acute toxicity of some heavy metals to different species of warmwater fishes. Air Water Pollut. Int. Jour. 10: 453.

Riva, M.C., *et al.* 1981. Lethal potassium dichromate and whitening (blankophor) exposure to goldfish (Carassius auratus): chromium level in gills. Comp. Biochem. Physiol. 68c:161.

Ruesink, R.G., and L.L. Jr. Smith. 1975. The relationship of the 96-Hr LC50 to the lethal threshold concentration of hexavalent chromium, phenol, and sodium pentachlorophenate. Trans. Am. Fish. Soc. 104(3): 567-570.

Sauter, S., *et al.* 1976. Effects of exposure to heavy metals on selected freshwater fish. Toxicity of copper, cadmium, chromium and lead to eggs and fry of seven fish species. EPA-600/3-76-105. National Technical Information Service, Springfield Virginia.

Stephenson, R.R. and S.A. Watts. 1984. Chronic toxicity tests with *Daphnia magna*: The effects of different food and temperature regimes on survival, reproduction and growth. Environ. Pollut. (Series A) 36: 95.

Trabalka, J.R. and C.W. Gehrs. 1977. An observation on the toxicity of hexavalent chromium to *Daphnia magna*. Toxicol. Letters 1: 131.

Trama, F.B. and R.J. Benoit. 1960. Toxicity of hexavalent chromium to bluegills. Jour. Water Pollut. Control Fed. 32: 868.

Waheda, M.F. 1977. Effect of size of fathead minnows (*Pimephales promelas*) and green sunfish (*Lepomis cyanellus*) on hexavalent chromium toxicity. Thesis. Wright State University, Dayton, Ohio.

White, A.M. Manuscript. The toxicity of hexavalent chromium ($Cr^{+6}$) to twenty-one species of aquatic animals native to Ohio.

White, B. 1979. Report of two toxicity evaluations conducted using hexavalent chromium. Michigan Department of Natural Resources.

**Trivalent Chromium (Cr III)**

Abbassi, S.A., P.C. Nipaney, and R. Soni. 1988. Studies on environmental management of mercury (II), chromium (VI) and zinc (II) with respect to the impact on some arthropods and protozoans. Int. J. Environ. Stud. 32: 181-187.

Anderson, B.G. 1948. The apparent thresholds of toxicity to *Daphnia magna* for chlorides of various metals when added to Lake Erie. Trans. Am. Fish. Soc. 78: 96.

Bills, T.D., *et al.* 1977. Effects of residues of the polychlorinated biphenyl Aroclor 1254 on the sensitivity of rainbow trout to selected environmental contaminants. Prog. Fish-Cult. 39: 150.

Boutet, C. and C. Chaisemartin. 1973. Specific toxic properties of metallic salts *in Austropotamobius pallipes pallipes* and *Arconectes limosus*. C.R. Soc. Biol. 167: 1933.

Chapman, G.A., *et al.* Manuscript. Effects of water hardness on the toxicity of metals to *Daphnia magna*. U.S. EPA, Corvallis, Oregon.

Fargasova, A. 1994. Toxicity of metals on *Daphnia magna* and *Tubifex tubifex.* Ecotoxicol. Environ. Saf. 27(2): 210-213.

Hale, J.G. 1977. Toxicity of metal mining wastes. Bull. Environ. Contam. Toxicol. 17: 66.

Marking, L.L. 1982. Letter to Quentin Pickering. National Fishery Research Laboratory, Lacrosse, Wisconsin. March 25.

Pickering, q.H. Manusript. Chronic toxicity of trivalent chromium to the fathead minnow (*Pimephales promelas*) in hard water. U.S. EPA, Cincinati, Ohio.

Pickering, Q.H. and C. Henderson. 1966. The acute toxicity of some heavy metals to different species of warmwater fishes. Air Water Pollut. Int. Jour. 10: 453.

Rehwoldt, R., *et al.* 1972. The effect of increased temperature upon toxicity of some heavy metal ions. Bull. Environ. Contam. Toxicol. 8: 91.

Rehwoldt, R., *et al.* 1973. The acute toxicity of some heavy metal ions toward benthic organisms. Bull. Environ. Contam. Toxicol. 10: 291.

Stackhouse, R.A. and W.H. Benson. 1989. The effect of humic acid on the toxicity and bioavailability of trivalent chromium. Ecotoxicol. Environ. Saf. 17(1): 105-111.

Stevens, D.G. and G.A. Chapman. 1984. Toxicity of trivalent chromium to early life stages of steelhead trout. Environ. Toxicol. Chem. 3: 125.

Warnick, S.L. and H.L. Bell. 1969. The acute toxicity of some heavy metals to different species of Aquatic insects. Hour. Water Pollut. Control Fed. 41: 280.

## 4.0 UNITS AND ACRONYMS

### UNITS

| | |
|---|---|
| mg/L | milligrams per litre |
| µg/L | micrograms per litre |
| % | percent |
| µS/cm | microSiemens per centimetre |
| NTU | nephelometric units |
| TCU | total colour units |
| TU | toxic units |

### ACRONYMS

| | |
|---|---|
| AEP | Alberta Environmental Protection |
| ACR | acute-chronic ratios |
| ARAMDG | Aquatic Risk Assessment and Mitigation Dialog Group |
| AQUIRE | Aquatic Information Retrieval database on Toxicity |
| CCME | Canadian Council of Ministers of the Environment |
| Cd | cadmium |
| Cr III | trivalent chromium |
| Cr VI | hexavalent chromium |
| Cu | copper |
| CWQG | Canadian Water Quality Guidelines |
| $EC_{50}$ | median effective concentration |
| EA | environmental assessment |

| | |
|---|---|
| ECOFRAM | ecological committee on FIFRA risk assessment methods |
| EOP | end of pipe |
| $HC_p$ | hazard concentration to some percentage *p* of species |
| $HC_5$ | hazard concentration to 5% of the species |
| $HC_{10}$ | hazard concentration to 10% of the species |
| $HC_{20}$ | hazard concentration to 20% of the species |
| HDS | High-density sludge |
| $H_2O_2$ | hydrogen peroxide |
| IC | inhibitive concentration |
| $IC_{25}$ | inhibitive concentration that indicates a concentration where 25 percent of the organisms had inhibited reproduction or growth |
| LC | lethal concentration |
| $LC_{50}$ | median lethal concentration |
| NAWQC | natural ambient water quality criteria |
| NOEC | no observable effect concentrations |
| ODEQ | Oregon Department of Environmental Quality |
| PKC | processed kimberlite containment |
| PAF | potentially affected fractions, or percent affected |
| PP8/HDS/$H_2O_2$ | high-density sludge removal with hydrogen peroxide oxidation |
| SOP | start of pipe |
| SSD | species sensitivity distribution |
| TSS | total suspended solids |
| UEOP | underground mine water |

| | |
|---|---|
| U.S. EPA | United States Environmental Protection Agency |
| WERF | Water Environmental Research Foundation |
| WET test | whole-effluent toxicity test |
| WMP | water management pond |