DE BEERS CANADA INC.

SNAP LAKE MINE

DEVELOPMENT OF FLUORIDE CHRONIC EFFECTS BENCHMARK FOR AQUATIC LIFE IN SNAP LAKE

December 2013

EXECUTIVE SUMMARY

Concentrations of fluoride measured in treated Snap Lake minewater have been consistently decreasing since 2004, ranging from greater than 1.2 milligrams per litre (mg/L) in 2005 to approximately 0.3 mg/L in 2012. However, fluoride concentrations remain elevated in Snap Lake with a maximum concentration of 0.18 mg/L reported in 2012. A fluoride chronic effects benchmark (CEB) is required as part of the *TDS Response Plan* that the Snap Lake Mine is required to submit to the Mackenzie Valley Land and Water Board by December 31, 2013. Fluoride is a constituent of total dissolved solids (TDS), although its contribution to the ionic composition of Snap Lake TDS is greater than 0.1 percent (%).

Available data on the acute and chronic toxicity of fluoride to freshwater aquatic life were compiled and reviewed. Acute toxicity occurs at fluoride concentrations ranging from 12 to greater than 800 mg/L. The majority of chronic effects occur at concentrations between 2.25 and 229 mg/L. A total of 11 chronic studies representing 15 species (3 fish, 8 invertebrates, and 4 algae/aquatic plants) were used to derive a CEB of 2.46 mg/L F^-, applying the species sensitivity distribution (SSD) approach recommended by the Canadian Council of Ministers of the Environment (CCME).

The above CEB is about 20-fold higher than the CCME fluoride fresh water quality guideline (WQG) set in 2002: 0.12 mg/L. However, that WQG did not use the SSD approach, nor did it consider the effect of increasing hardness in reducing fluoride toxicity. British Columbia (BC) has a provincial WQG for fluoride that is hardness-dependent; the BC WQG would be 1.47 mg/L at the current Snap Lake water hardness of 140 mg/L as calcium carbonate ($CaCO_3$), which is within a factor of two of the CEB derived above and about 10-fold higher than the 2002 CCME fluoride WQG. However, the BC WQG was derived from a single study that used acute data for Rainbow Trout at different hardness concentrations rather than the SSD approach; thus, the BC WQG is not as robust as the CEB calculated herein using multiple chronic studies and applying the CCME SSD approach. Accordingly, the CEB derived herein (2.46 mg/L F^-) is recommended as a site-specific water quality objective (SSWQO) for fluoride in Snap Lake.

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AEMP	Aquatic Effects Monitoring Program
BC	British Columbia
BCMOE	British Columbia Ministry of Environment
$CaCO_3$	calcium carbonate
CCME	Canadian Council of Ministers of the Environment
CEB	chronic effects benchmark
Cl^-	chloride ion
De Beers	De Beers Canada Inc.
EAR	Environmental Assessment Report
ECx	concentrations of sample estimated to cause a specified effect to x% of the test organisms
EQC	effluent quality criterion
F^-	fluoride ion
HC5	hazardous concentration to 5% of species
ICx	the inhibiting concentration for an x% effect; the concentration of sample estimated to cause x% reduction in growth or fecundity of the test organisms
LCx	concentrations of sample estimated to be lethal to x% of the test organisms
LOEC	lowest observed effect concentration
MATC	maximum acceptable toxicant concentration; the geometric mean of the NOEC and LOEC
Mine	Snap Lake Mine
MVLWB	Mackenzie Valley Land and Water Board
NaF	sodium fluoride
NOEC	no observed effect concentration
NWT	Northwest Territories
SMCV	species mean chronic value
SNP	Surveillance Network Program
SSD	species sensitivity distribution
SSWQO	site-specific water quality objective
TDS	total dissolved solids
USEPA	United States Environmental Protection Agency
WQG	water quality guideline

UNITS OF MEASURE

%	percent
<	lower than
>	greater than
±	plus or minus
°C	degrees Celsius
µg/L	micrograms per litre
d	days
h	hours
km	kilometre
mg/L	milligrams per litre
mg/L F^-	milligrams per litre fluoride

1 INTRODUCTION

De Beers Canada Inc. (De Beers) owns and operates the Snap Lake Mine (Mine) in the Northwest Territories (NWT). The Mine is located approximately 220 kilometres (km) northeast of Yellowknife, 30 km south of MacKay Lake, and 100 km south of Lac de Gras where the Diavik Diamond Mine and EKATI Diamond Mine are located. Final regulatory approvals for construction and operation of the Mine were granted in May 2004, and construction began in April 2005. The Mine officially opened on July 25, 2008.

To comply with the Mine's Water Licence (Water Licence MV2001L2-0002, renewed as MV2011L2-0004 in 2012; MVLWB 2012), De Beers is required to undertake water quality monitoring as part of a larger Aquatic Effects Monitoring Program (AEMP) that also includes monitoring of sediment quality, plankton, benthic invertebrates, and fish in Snap Lake. The AEMP water quality component includes monitoring of fluoride concentrations in Snap Lake; these data are submitted in annual AEMP reports to the Mackenzie Valley Land and Water Board (MVLWB) (e.g., De Beers 2013a). In addition, De Beers is required to monitor the quality of its treated effluent discharge as part of its Surveillance Network Program (SNP), results of which are also submitted to the MVLWB.

Fluoride is present in Snap Lake primarily as a result of seepage of shallow groundwater into the underground Mine (Drysdale 2011). The 2002 Environmental Assessment Report (EAR; De Beers 2002) did not make predictions about changes to fluoride concentrations in Snap Lake over the operational life of the mine. No benchmark for fluoride was proposed in the EAR, although an interim Canadian water quality guideline (WQG) for protection of freshwater aquatic life was subsequently developed for fluoride and adopted as the AEMP benchmark for Snap Lake. Fluoride concentrations in Snap Lake were measured at concentrations above the AEMP benchmark in 2012; therefore, a site-specific fluoride benchmark needs to be developed for Snap Lake to determine whether there is a risk of adverse effects above the current AEMP benchmark.

The Mine's Water Licence requires that a *TDS Response Plan* be submitted to the MVLWB by December 31, 2013. One component of that *TDS Response Plan* is to provide recommendations and supporting rationale for site-specific water quality objectives (SSWQOs) for total dissolved solids (TDS), chloride, and fluoride in Snap Lake, derived from toxicity tests conducted by De Beers and/or published toxicology studies. A second component is to provide recommendations and supporting rationale for effluent quality criteria (EQC) for those parameters. Development of SSWQOs for TDS and chloride is reported separately (Golder 2013).

The purpose of this report is to address the requirement of the *TDS Response Plan* that a SSWQO be developed for fluoride. This report reviews existing fluoride benchmarks, provides an overview of environmental concentrations of fluoride associated with Snap Lake, summarizes available information on the toxicity of fluoride to freshwater aquatic life, and proposes a chronic effects benchmark (CEB) for fluoride in Snap Lake.

2 WATER QUALITY BENCHMARKS FOR FLUORIDE

The Canadian Council of Ministers of the Environment (CCME 2002) established a national WQG for total inorganic fluoride for protection of freshwater aquatic life of 0.12 milligrams per litre (mg/L). This was an interim WQG because there were insufficient toxicity data available at that time to derive a full WQG. The interim WQG was derived following CCME (1991) methodology, which provided three approaches depending on data availability: multiplying the most sensitive Lowest Observed Effect Concentration (LOEC) from an acceptable chronic study by a safety factor of 0.1; dividing the most sensitive LC50 or EC50 from an acceptable acute study by an appropriate acute-to-chronic ratio; or, multiplying the most sensitive LC50 or EC50 from an acceptable acute study by an application factor (0.05 for nonpersistent substances; 0.01 for persistent substances). Available data on fluoride toxicity were compiled and reviewed as part of the WQG derivation process (Environment Canada 2001). There were insufficient data from acceptable chronic toxicity studies; therefore, the interim WQG was derived by multiplying the 144-hour (h) acute LC50 of 11.5 mg/L fluoride (F^-) for the caddisfly *Hydropsyche bronta* (Camargo et al. 1992a) by an application factor of 0.01.

British Columbia (BC) has an interim provincial WQG for total fluoride that is hardness dependent (BCMOE 1995); this WQG is considered interim until additional studies on the influence of temperature and water hardness on fluoride toxicity can be conducted. At a water hardness of 10 mg/L as calcium carbonate ($CaCO_3$) the provincial fluoride WQG is 0.4 mg/L; otherwise it is calculated using the following hardness-dependent equation:

$$\text{WQG}(hardness) = -51.73 + 92.57\ \text{Log}_{10}(hardness), \text{multiplied by } 0.01$$

This hardness-dependent equation was developed by Pimentel and Bulkley (1983) using 96-h LC50s from acute toxicity tests performed with juvenile Rainbow Trout (*Oncorhynchus mykiss*) at a range of water hardness concentrations. Because the hardness-dependent equation is intended to estimate 96-h LC50s for fluoride relative to water hardness, a 0.01 LC50-to-chronic uncertainty factor is applied to derive the WQG. The current water hardness in Snap Lake is approximately 140 mg/L as $CaCO_3$; applying the BC hardness-dependent equation would result in a SSWQO of 1.47 mg/L.

Manitoba has a surface WQG for inorganic fluorides of 0.12 micrograms per litre (µg/L) for protection of freshwater aquatic life (Manitoba Water Stewardship 2011); this is intended to be the CCME (2002) WQG but appears to use incorrect concentration units.

The United States does not have a national benchmark for protection of freshwater aquatic life for fluoride. North Carolina has a surface water quality standard of 1.8 mg/L for protection of freshwater aquatic life (NCDENR 2003).

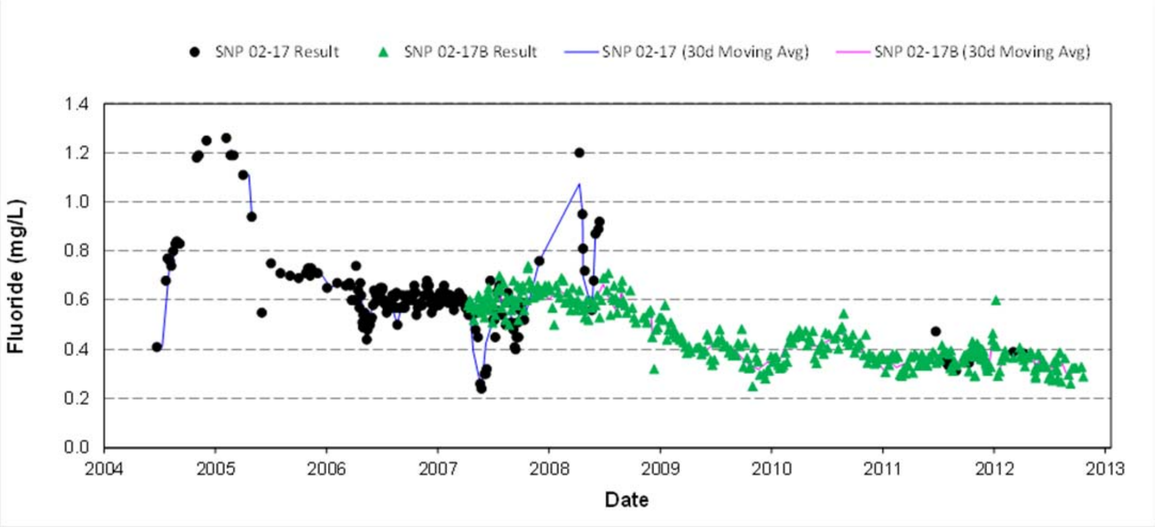
3 ENVIRONMENTAL CONCENTRATIONS OF FLUORIDE IN SNAP LAKE

Information on total fluoride concentrations measured in treated effluent and in water samples collected from Snap Lake and associated reference lakes is briefly summarized below. These data have previously been provided to the MVLWB as part of the EAR, and/or in AEMP and SNP monitoring reports. Data from October 2012 were the most recent data available[1] for inclusion herein. Fluoride concentrations are not monitored in sediments or fish tissues in Snap Lake or the reference lakes.

3.1 Treated Effluent

Concentrations of total fluoride measured in treated effluent from the temporary water treatment plant (Station SNP02-17) and the permanent water treatment plant (Station SNP02-17B) between 2004 and 2012 are shown in Figure 1. Individual measurements as well as 30-day (d) moving averages for each discharge point are shown. Fluoride concentrations in treated effluent have been consistently decreasing since 2004, ranging from more than 1.2 mg/L in 2005 to approximately 0.3 mg/L in 2012. There are currently no EQC set for fluoride in the Water Licence; however, as of January 1, 2015, in the absence of a SSWQO the Water Licence specifies EQC of 0.15 mg/L as the maximum average monthly concentration and 0.3 mg/L as the maximum concentration in any grab sample.

Figure 1: Fluoride Concentrations in Treated Effluent, 2004 to 2012



30d Moving Avg = 30-day moving average; SNP 02-17 = treated effluent from the temporary water treatment plant; SNP 02-17B = treated effluent from the permanent water treatment plant; mg/L = milligrams per litre.

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[1] Data collected in 2013 are undergoing screening and compilation as part of preparation for the 2013 AEMP report and were therefore not available for inclusion.

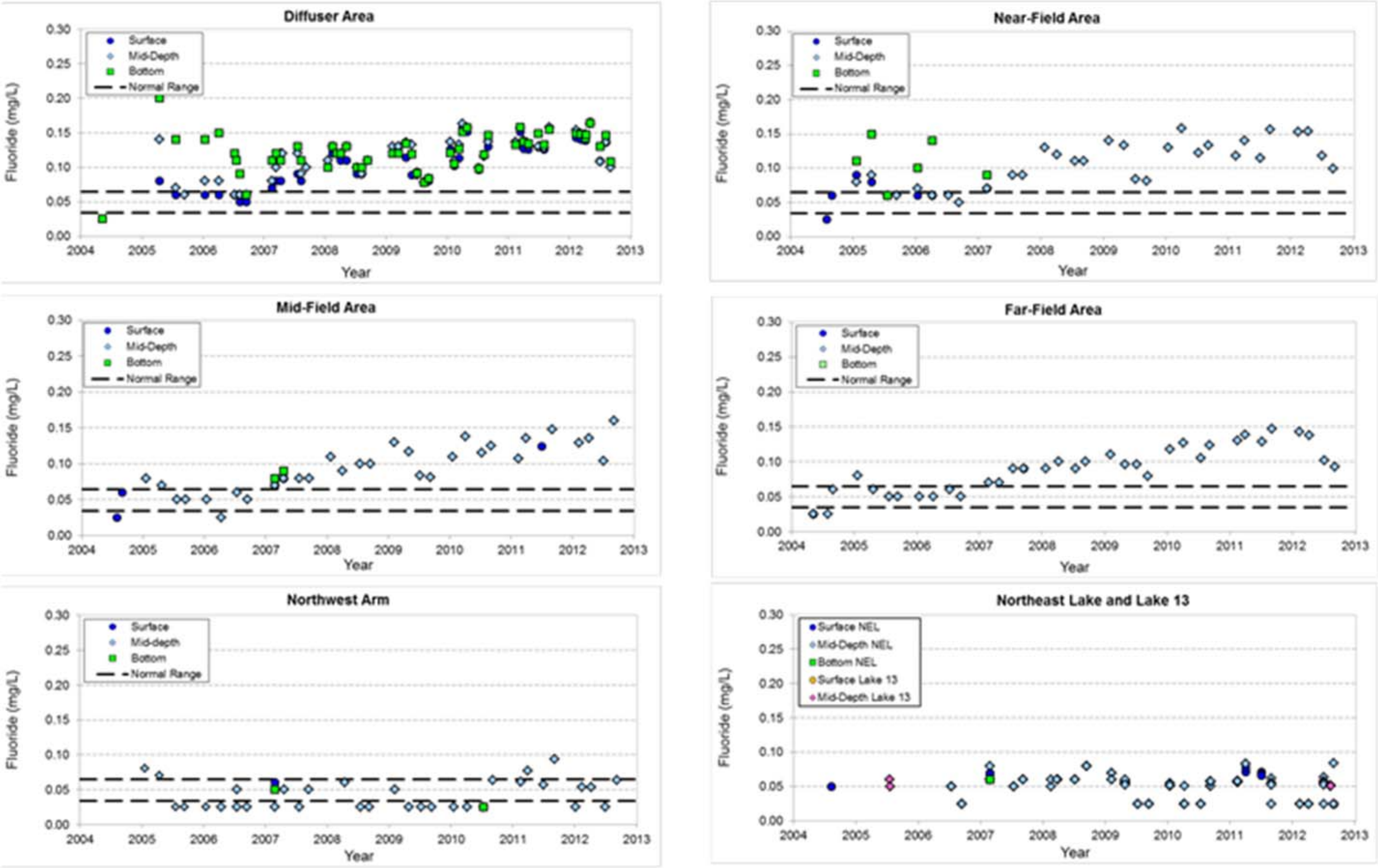
3.2 Snap Lake Water

Concentrations of total fluoride measured in Snap Lake water between 2005 and 2012 are shown in Figure 2 for the five different areas of the lake: diffuser; near-field; mid-field; far-field; and, northwest arm. Concentrations measured in the Northeast Lake and Lake 13 reference lakes are also provided.

Baseline water quality of Snap Lake was characterized through analyses of water samples collected in 1999 and 2001; results from those analyses were reported in the EAR (De Beers 2002). Baseline concentrations of total fluoride in Snap Lake ranged from 0.04 to 0.06 mg/L. Fluoride concentrations have increased in Snap Lake since Mine operations began, and have been above the CCME WQG since 2008. In 2012, the maximum fluoride concentration measured in Snap Lake was 0.18 mg/L; the average concentrations for the five lake areas ranged from 0.05 to 0.13 mg/L. In 2012, fluoride concentrations were 0.08 mg/L in Northeast Lake and 0.05 mg/L in Lake 13. Preliminary review of 2013 water chemistry data for Snap Lake indicates that fluoride concentrations remain elevated, with a maximum concentration of 0.23 mg/L reported at a diffuser station.

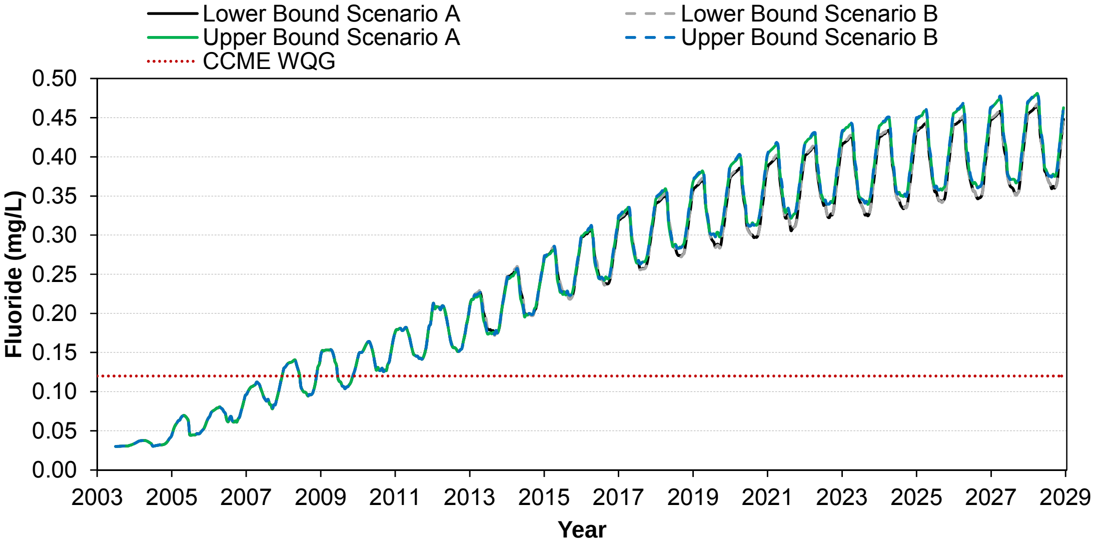
The 2013 model results (De Beers 2013b) indicated that fluoride concentrations were predicted to increase from approximately 0.20 mg/L in 2012 to 0.50 mg/L in 2028 at the diffuser stations and at the outlet of Snap Lake (Figure 3-3).

Figure 2: **Concentrations of Fluoride in Water in Five Areas of Snap Lake, and in the Northeast Lake and Lake 13 Reference Lakes, 2004 to 2012**

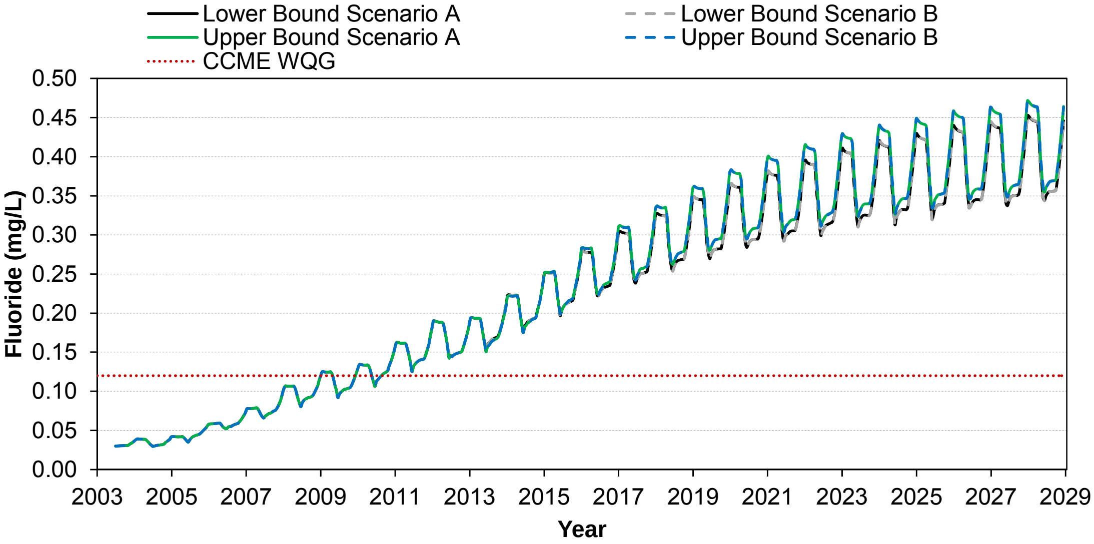


Note: mg/L = milligrams per litre; normal range is based on data collected prior to 2004, with the upper and lower range calculated as the mean ± 2 standard deviations.

Figure 3: **Predicted Fluoride Concentrations in Snap Lake**



[(a)] Near diffuser, SNP 02-20e



[(b)] Outlet, SNAP07

mg/L = milligrams per litre; CCME = Canadian Council of Ministers of the Environment; SNP = surveillance network program; WQG = water quality guideline.

4 TOXICITY OF FLUORIDE TO FRESHWATER AQUATIC LIFE

Available acute and chronic toxicity data for freshwater fish, invertebrates, algae, and aquatic plants are tabulated in Appendix A. This included information compiled by Fleiss (2011). Because the objective of this review was to develop a CEB for fluoride, only the chronic and sub-chronic toxicity studies are summarized below. Test endpoints are expressed in terms of the concentration of fluoride, not the inorganic salt (i.e., mg/L F^-, not mg/L sodium fluoride [NaF]).

Definitions for test endpoints are provided. The LC*x* is the concentration of test material estimated to be lethal to "*x*" percent of the test organisms, (e.g., LC50); the ECx is the concentration of test material estimated to cause a specified non-lethal effect to "*x*" percent of the test organisms (e.g., EC50). The IC*x* is the concentration of test material estimate to cause "*x*" percent inhibition in a sublethal endpoint such as growth or reproduction. The no observed effect concentration (NOEC) is the highest concentration tested where there was no statistically significant response compared to the negative control. The LOEC is the lowest concentration tested where there was a statistically significant response relative to the negative control. The MATC is the geometric mean of the NOEC and LOEC.

The criteria provided by CCME (2007) were used to determine whether a test was considered chronic (i.e., sufficient test duration or life stage sensitivity) and could therefore be included in the species sensitivity distribution (SSD) for derivation of the fluoride CEB. For example, exposure periods ≥21 days (or ≥7 days for eggs and larvae) were considered chronic for fish toxicity endpoints. For invertebrates, sublethal endpoints from exposure periods ≥4 days were considered chronic for short-lived invertebrates (e.g., *Ceriodaphnia dubia*) or from ≥7-day exposures for invertebrates with longer life-cycles (e.g., crayfish). For invertebrates, lethal endpoints were only considered chronic if the exposure period was ≥21 days. Sub-chronic data represented endpoints from tests where the exposure duration was longer than for acute tests but not as long as specified for chronic tests (e.g., invertebrate mortality tests between 4 and 21 days); these were considered on a case-by-case basis. If sufficient chronic data were not available for a species, sub-chronic data were considered: CCME (2007) allows inclusion of a sub-chronic endpoint in an SSD if the test is for a sensitive lifestage such as larval development and no additional chronic data are available for that particular species. Data from acute toxicity tests were excluded from the SSD derivation.

4.1 Fish

Angelovic et al. (1961) conducted 10-d tests with juvenile Rainbow Trout, using sodium fluoride. The fish were exposed to fluoride concentrations of 0 to 25 mg/L F^- at four temperatures: 7.5, 13, 18, and 24 degrees Celsius (°C). Tests were conducted at a low hardness; the dilution water was passed through a commercial softener to remove excess calcium and magnesium prior to adding the fluoride. Survival was the only endpoint measured. Point estimates could not be determined at 24°C, due to high mortality in multiple treatments. Probit equations were reported for each test temperature and used here to calculate the following point estimates: LC10s of 4.1, 2.2, and 1.8 mg/L; and, LC50s of 6.6, 3.9, and 4.8 mg/L at 7.5°C, 13°C, and 18°C, respectively. This study showed that Rainbow Trout sensitivity to fluoride increased with increasing temperature. This test duration was sub-chronic as defined in Section 4.0; this study was not used for CEB derivation because sufficient chronic data were available from other studies as detailed below.

Herbert and Shurben (1964) conducted 21-d static-renewal tests with Rainbow Trout yearlings (~10 cm). Tests were conducted at 14.5°C, at three water hardness concentrations: 12, 45, and 320 mg/L as $CaCO_3$. Mortality was the only endpoint measured. For the test conducted at 12 mg/L as $CaCO_3$, the LC5, LC10, LC20, and LC50 values were 4, 5, 6, and 8.5 mg/L, respectively. The test conducted at 45 mg/L as $CaCO_3$ had 100% survival at 75 mg/L and zero survival at 113 mg/L. The test conducted at 320 mg/L as $CaCO_3$ had 100 percent (%) survival at 100 mg/L and zero survival at 200 mg/L. In the toxicity tests conducted at the two higher hardness concentrations, precipitation was observed after fluoride (as sodium fluoride) was introduced into the exposure system, resulting in daily variation in dissolved fluoride concentrations. For this reason, Rainbow Trout survival could not be accurately related to the fluoride concentration in those two tests. Thus, only the 21-d LC10 for the test conducted at 12 mg/L as $CaCO_3$ was included for the CEB determination.

Banack et al. (2012) conducted 7-d survival and growth tests with Rainbow Trout fry to assess the potential effects of chloride as a modifying factor on fluoride toxicity. The tests were conducted at a water hardness of 6 mg/L as $CaCO_3$ and chloride concentrations of 2, 6, and 18 mg/L Cl^-. The IC25 values for growth at each chloride concentration were 10.3, 12.3, and 31.5 mg/L F^-, respectively, which showed that in soft water the toxicity of fluoride to Rainbow Trout decreased as the chloride concentration increased. This test duration was sub-chronic; it was not used for CEB determination again because sufficient chronic data were available for this species.

Neuhold and Sigler (1960) conducted fluoride toxicity tests with different life stages of Rainbow Trout in soft water (7.5 mg/L as $CaCO_3$) at a range of temperatures. The authors reported LC50s as a range of fluoride concentrations representing 95% confidence levels rather than discrete point estimates; where possible, point estimates were determined using equations or plots provided in the original publication. A 20-d test was conducted at 12.8°C using fish that were 10 to 20 cm long; the 20-d LC10, LC20, and LC50 were estimated to be 1.5, 2.0, and 3.6 mg/L F^-, respectively. Tests with 20-d old fertilized eggs conducted at three temperatures had similar LC50s but test durations were shorter as temperature increased. At 7.7°C the 18-d LC50 was between 222 and 273 mg/L F^-; at 12.8°C the 9-d LC50 was between 242 and 261 mg/L F^-; and, at 15.5°C the 7-d LC50 was between 237 and 281 mg/L F^-. A 34-d test conducted with 20-d old fertilized eggs at 15.5°C had an estimated LC50 for fry survival of 76 mg/L F^-. Results from these tests indicated that Rainbow Trout eggs and fry were less sensitive to fluoride than older fish, presumably because the younger life stages do not begin feeding until after hatching and yolk sac absorption. The 34-d LC50 of 76 mg/L F^- was included for CEB determination as this was the lowest chronic test result, whereas the other exposure durations were sub-chronic.

Banack et al. (2012) conducted 7-d survival and growth with larval Fathead Minnow (*Pimephales promelas*), to assess the potential effects of chloride as a modifying factor for fluoride toxicity. The tests were conducted at a hardness of 86 to 90 mg/L as $CaCO_3$ and chloride concentrations of 2, 6, and 18 mg/L Cl^-. The IC25 values for growth at each chloride concentration were 82.2, 63.1, and 93.2 mg/L F^-, respectively. Unlike similar testing with juvenile Rainbow Trout, increasing chloride concentrations did not modify fluoride toxicity for Fathead Minnow. The IC25 of 63.1 mg/L F^- was included for CEB determination because it was the lowest chronic endpoint.

Metcalfe-Smith et al. (2003) conducted 7-d survival and growth tests with larval Fathead Minnow at two water hardness concentrations. At 160 mg/L as $CaCO_3$ the LC25 for survival was 132 mg/L F^- and the IC25 for growth was 72 mg/L F^-. At 280 mg/L as $CaCO_3$ the LC25 for survival was 145 mg/L F^- and the IC25 for growth was 94 mg/L F^-. These results showed that the toxicity of fluoride to larval Fathead Minnow decreased as hardness increased. The IC25 of 72 mg/L F^- was included for CEB determination because the water hardness was similar to that of Snap Lake and it was the lowest chronic endpoint.

Neuhold and Sigler (1960) conducted a 20-d fluoride toxicity test with Common Carp, *Cyprinus carpio*, that were 10 to 36 cm long. The test was conducted in soft water (7.5 mg/L as $CaCO_3$) at 18°C to 24°C. The 20-d LC20 and LC50 were estimated as 25 and 81 mg/L F^-, respectively. This test duration was sub-chronic; thus, it was not used for CEB determination.

Cao et al. (2013) exposed juvenile Common Carp to fluoride concentrations ranging from 35 to 124 mg/L F^- for 90 days. The test was conducted at 22°C at a water hardness of 20 mg/L as $CaCO_3$; the fluoride concentration in the control was 1.8 mg/L F^-. Following exposure to fluoride, enzyme activity assays were performed on gill tissues to measure superoxide dismutase, Na^+-K^+-ATPase, and Ca^{2+}-ATPase levels. For superoxide dismutase and Ca^{2+}-ATPase activities, the NOEC and LOEC were 63.3 and 77.7 mg/L F^-, respectively, and the MATC was 70.1 mg/L F^-. For Na^+-K^+-ATPase activities, the NOEC and LOEC were 77.7 and 124.4 mg/L F^-, respectively, and the MATC was 98.3 mg/L F^-. These endpoints were based on biomarker responses, whose relationship to whole body effects is uncertain; thus, they were not included in the SSD.

Shi et al. (2009) conducted a 90-d fluoride growth study using juvenile Siberian Sturgeon *(Acipenser baerii*). The test was performed at 23°C and a hardness of 22 mg/L as $CaCO_3$. The fluoride concentration in the control was 0.26 mg/L F^-; no mortalities occurred. No mortalities occurred during testing so the LC10 and LC20 for survival were greater than 51.8 mg/L F^- (the highest tested concentration). The NOEC and LOEC for growth were 3.1 and 7.8 mg/L F^-, respectively. The MATC, calculated as the geometric mean of the NOEC and LOEC, was 4.9 mg/L F^-. Point estimates for the growth endpoint were calculated from mean body weights reported for each fluoride concentration; the IC10 was estimated as 7.7 mg/L F^- and the IC20 was more than 51.8 mg/L F^-. The IC10 of 7.7 mg/L F^- was included for CEB determination as this was the lowest chronic endpoint.

Wright (1977) conducted a 10-d fluoride toxicity test with Brown Trout fry (*Salmo trutta*) that were less than eight weeks old and had just absorbed their yolk sac. The test was performed at 12°C and a water hardness of 73 mg/L as $CaCO_3$. The fluoride concentration in the control was 0.9 mg/L F^-; no mortalities occurred. An acute (100-h) LC50 of 15 mg/L F^- was estimated. A 10-d LC10 for survival could not be estimated from the available data, but a 10-d LC20 for survival of 5 mg/L F^- was estimated. This 10-d test duration was sub-chronic; thus, it was not used for the CEB determination.

4.2 Invertebrates

Dave (1984) conducted a 21-d survival and reproduction toxicity test with less than 24-h old neonates of the water flea, *Daphnia magna*. The test was conducted at 20.5°C at a hardness of 250 mg/L as $CaCO_3$. Survival, body length, and reproduction were the endpoints measured. For all three endpoints, the NOEC and LOEC were 3.7 and 7.4 mg/L F^-, respectively. For each endpoint, the MATC was calculated to be 5.2 mg/L F^-. Mean control survival was 83% after 14 days, but only 55% after 21 days; this low level of control survival was not considered acceptable, and therefore results from this test were not used in the CEB determination.

Fieser et al. (1986) conducted a 21-d survival and reproduction toxicity test with less than 24-h old neonates of *D. magna*. The test was conducted at 20°C and a target water hardness of 181 mg/L as $CaCO_3$; the actual hardness decreased with increasing fluoride concentration and ranged from 102 to 181 mg/L as $CaCO_3$. Mortality was low among treatments and the LC10 and LC20 for survival were greater than 142 mg/L F^-. The IC10 and IC20 for reproduction were estimated to be 27.7 and 29.4 mg/L F^-, respectively. The IC10 of 27.7 mg/L F^- was included for the CEB determination as this was the lowest chronic endpoint.

Banack et al. (2012) conducted 7-d survival and reproduction toxicity tests with less than 24-h old neonates of the water flea, *Ceriodaphnia dubia*, to assess the effects of chloride on fluoride toxicity. The tests were conducted at 25°C and a water hardness of 82 to 88 mg/L as $CaCO_3$; the chloride concentrations were 2, 6, and 18 mg/L Cl^-. At the three chloride concentrations tested, the IC25s for reproduction were 17.2, 12.7, and 11.2 mg/L F^-, respectively. For *C. dubia*, fluoride toxicity increased as the chloride concentration increased. The IC25 of 11.2 mg/L F^- was included for the CEB determination as this was the lowest chronic endpoint.

Banack et al. (2012) conducted 14-d survival and growth toxicity tests with juvenile amphipods, *Hyalella azteca*, to assess the effects chloride on fluoride toxicity. The tests were conducted at 23°C and a water hardness of 88 to 90 mg/L as $CaCO_3$; the chloride concentrations were 2, 6, and 18 mg/L Cl^-. At the three chloride concentrations tested, the IC25s for growth were 2.8, 5.1, and 7.1 mg/L F^-, respectively. Unlike *C. dubia*, fluoride toxicity to *H. azteca* decreased as the chloride concentration increased. The IC25 of 2.8 mg/L F^- was included for the CEB determination as this was the lowest chronic endpoint.

Banack et al. (2012) conducted a 10-d survival and growth toxicity test with the juvenile midge, *Chironomus dilutus* (formerly *C. tentans*). The test was conducted at 23°C, a water hardness of 90 mg/L as $CaCO_3$, and a chloride concentration of 2 mg/L Cl^-. The IC25 for growth was 11.5 mg/L F^-; this chronic endpoint was included in the CEB determination.

Casellato et al. (2013) conducted 18-d toxicity tests with the oligochaete worm, *Branchiura sowerbyi*, at two temperatures; the water hardness was not reported. Tests were performed with a sediment substrate. At 17°C, mortality in all three fluoride treatments was estimated to be 5% and therefore the LC10 and LC20 for survival were greater than 160 mg/L F^-. In the test performed at 22°C, mortality increased by 1.2% for every 10 mg/L F^-, and the LC10 and LC20 for survival were estimated to be 40 and 60 mg/L F^-, respectively. Casellato et al. (2013) also conducted a 5-month study to assess the effects of fluoride on gametogenesis of *B. sowerbyi*; the test was conducted at 23°C and the water hardness was not reported. Gametogenesis was impaired at 6.8 and 13.6 mg/L F^- but the magnitude of the effects relative to the control was not reported for both treatments. In the higher fluoride concentration, *B. sowerbyi* did not complete spermatozoan maturation, the number of mature eggs produced was largely reduced, and the male line stopped maturation at the spermatid stage. Overall, the worms in the fluoride treatments were thinner and shorter and cocoon deposition did not occur. The 18-d test duration was sub-chronic; it was not used for the CEB determination. The 5-month study did not provide a clear endpoint for use in the SSD.

Alonso and Camargo (2011) conducted a 28-d survival and reproduction test with the New Zealand mud snail, *Potamopyrgus antipodarum*. The test was conducted at 12°C and a water hardness of 97 mg/L as $CaCO_3$. For survival, no statistically significant adverse effects were observed in the fluoride treatments; therefore, the NOEC for survival was 16.2 mg/L F^-. Reproduction endpoints were newborn production during the 28-d exposure, and numbers of embryos present on the six longest specimens (the novel second sublethal endpoint used by these authors) at the end of the 28-d exposure. For newborn production, the NOEC and LOEC were 4.6 and 9.5 mg/L F^-, respectively, and the MATC was 6.6 mg/L F^-. For numbers of embryos, the NOEC and LOEC were 9.5 and 16.2 mg/L F^-, respectively, and the MATC was 12.4 mg/L F^-. The lower MATC of 6.6 mg/L F^- for newborn production (a standard sublethal endpoint) was included for the CEB determination.

Keller and Augspurger (2005) conducted 9-d survival and growth toxicity tests with juveniles of two species of unionid mussels: Appalachian elktoe (*Alasmidonta raveneliana)* and Wavy-rayed Lampmussel (*Lampsilis fasciola)*. The tests were conducted at 25°C and a water hardness of 28 to 32 mg/L as $CaCO_3$. The 9-d LC50s for survival were 223 mg/L F^- for *A. raveneliana* and 177 mg/L F^- for *L. fasciola.* Growth (shell length) was measured for *A. raveneliana* but not *L. fasciola*. Growth was significantly reduced in all three fluoride concentrations relative to the control; the LOEC for shell length was 31 mg/L F^- and an IC10 of 91 mg/L F^- was calculated from the shell length data. This IC10 (a preferential endpoint compared to the LOEC) of 91 mg/L F^- for *A. raveneliana* growth was included for the CEB determination.

Sparks and Sandusky (1983) conducted an 8-week survival and growth toxicity test with juvenile fingernail clams, *Musculium transversum*. The test was conducted at 21°C and a water hardness of 232 mg/L as $CaCO_3$. The fluoride concentration in the control was 0.12 mg/L F^-. After 8 weeks, mortality in the control treatment was 25%. The NOEC and LOEC for survival were 1.80 and 2.82 mg/L F^-, respectively; the MATC was 2.25 mg/L F^-. There was at least 50% survival in all test treatments, so the LC50 for survival was greater than 4.56 mg/L F^- (the highest tested fluoride concentration). There were no adverse effects on growth (shell length) at the fluoride concentrations tested, so the NOEC for growth was 4.56 mg/L F^- and the IC10 and IC20 were greater than 4.56 mg/L F^-. The MATC of 2.25 mg/L F^- was included for the CEB determination as this was the lowest chronic endpoint.

Del Piero et al. (2012) conducted 17-week tests with adult zebra mussels, *Dreissena polymorpha.* Water hardness was 106 mg/L as $CaCO_3$, and tests were performed at two temperatures. In the test conducted at 17°C, a 17-week LC20 for survival could not be determined but the LC50 was estimated to be 10 mg/L F^-. In the test conducted at 22°C, the mussels were dead in all treatments by 11 weeks; an 8-week LC50 of 10 mg/L F^- was estimated. The 17-week chronic LC50 of 10 mg/L F^- was included for the CEB determination.

Aguirre-Sierra et al. (2013) conducted an 8-day toxicity test with white-clawed crayfish, *Austropotamobius pallipes*. The test was conducted at 19.5°C, at a water hardness of 190 mg/L as $CaCO_3$. The 8-d LC50 for survival was 28.9 mg/L F^-; the NOEC and LOEC were 19.4 and 45.1 mg/L F^-, respectively, and the MATC was 29.6 mg/L F^-. Behaviour was also assessed, in terms of an escape response (i.e., a tail flip when the organism was tapped on the abdomen three times); the EC50 for the escape response was 5.9 mg/L F^-. The 8-d test duration was sub-chronic; it was not used for the CEB determination.

4.3 Algae and Aquatic Plants

Banack et al. (2012) conducted a 72-h algal growth toxicity test with the green phytoplankton, *Pseudokirchneriella subcapitata*. The test was conducted at 25°C; the water hardness was 14 mg/L as $CaCO_3$ and the chloride concentration was 4 mg/L Cl^-. Inhibition of algal growth was the endpoint measured. The IC25 for growth inhibition was 217 mg/L F^-; this chronic endpoint was included for the CEB determination.

Joy and Balakrishnan (1990) conducted a 96-h algal growth test with the diatom, *Nitzchia palea*. Algal growth was stimulated at all fluoride concentrations from 10 to 110 mg/L F^-. Because the endpoint for this test method is inhibition of algal growth, there were no adverse effects in any treatment and the NOEC for growth inhibition was greater than 110 mg/L F^-. This test was not included for the CEB determination.

Hekman and Budd (1984) conducted algal growth toxicity tests with six species of phytoplankton: *Ankistrodesmus braunii*, *Cyclotella meneghiniana*, *Oscillatoria limnetica*, *Scenedesmus quadricauda*, *Stephanodiscus minutus*, and *Synechococcus leopoliensis*. The test temperature was 23°C, except *S. minutus* that was tested at 15°C; water hardness was not reported. Growth inhibition was not observed at the highest fluoride concentration tested for *A. braunii*, *C. meneghiniana*, *O. limnetica*, *S. quadricauda*, and *S. minutus*; therefore, an unbounded NOEC of greater than 50 mg/L F^- was determined for those five test species. For *S. leopoliensis*, the NOEC, LOEC, and MATC for growth inhibition were 25, 50, and 36 mg/L F^-, respectively; there was a 13% reduction in algal growth at 50 mg/L F^- so that concentration was used as an EC13 estimate (per CCME 2007 a preferential endpoint to the NOEC, LOEC, or MATC) and included in the CEB determination.

Rai et al. (1998) conducted 15-d chronic toxicity tests with the green phytoplankton, *Chlorella vulgaris,* investigating the pH-induced toxicity of $AlCl_3$, AlF_3, NaF, and $AlCl_3$ + NaF. Tests were conducted at 26°C, at pH values of 4.5, 6, and 6.8. Survival and growth were the biological endpoints measured. For organisms tested at pH 6.8 and 6, the LC50s were 840 and 588 mg/L F-, respectively, in 15-day exposures. A 3-d LC50 of 294 mg/L F^- was reported for organisms tested at pH 4.5. The concentration at which algal growth inhibition was observed for 11% of the test population (IC11) was 95 mg/L F- in the 15-day exposures; this IC11 was included in the CEB determination.

Banack et al. (2012) conducted a 7-d toxicity test with duckweed, *Lemna minor*. The test was conducted at 25°C; the water hardness was 206 mg/L as $CaCO_3$ and the chloride concentration was 73 mg/L Cl^-. Reproduction/growth was the biological endpoint measured; the IC25 of 229 mg/L F^- was included in the CEB determination.

Oota (1971) conducted toxicity tests with duckweed (*Lemna gibba*). Tests were conducted at 26°C for 3 days; the water hardness was not reported. Growth and flower germination were the biological endpoints measured. From plots provided in the paper, an EC10 of 4.2 mg/L F^- for growth as well as an EC18 and EC50 of 0.42 and 4.2 mg/L F^-, respectively, for flower germination were estimated. Due to the short test duration and lack of experimental details of the study, results from this study were not included in the CEB determination.

4.4 Toxicity Modifying Factors

Fluoride toxicity can be affected by a number of modifying factors, particularly temperature and water hardness, but also chloride concentration. The influence of these modifying factors is not necessarily consistent among different species. Information on these modifying factors and their relationship to fluoride toxicity is summarized below.

Angelovic et al. (1961) conducted 10-d fluoride tests with Rainbow Trout at temperatures ranging from 7.5 to 24°C, and found that fluoride toxicity increased with increasing temperature.

Fieser et al. (1986) conducted acute tests with *D. magna* at 15, 20, and 25°C and a water hardness of 170 mg/L as $CaCO_3$ and reported 48-h LC50s of 304, 251, and 200 mg/L F-, respectively. The relationship between increasing temperature and increased fluoride concentration was described by the equation: LC50 = (6.93 – 0.065T), where “T” represents temperature.

Metcalfe-Smith et al. (2003) conducted 7-d survival and growth tests with larval Fathead Minnow at two water hardness concentrations. At 160 mg/L as $CaCO_3$ the LC25 for survival was 132 mg/L F^- and the LC25 for growth was 72 mg/L F^-. At 280 mg/L as $CaCO_3$ the LC25 for survival was 145 mg/L F^- and the IC25 for growth was 94 mg/L F^-. The toxicity of fluoride to larval Fathead Minnow decreased as hardness increased.

Pimentel and Bulkley (1983) conducted static 96-h toxicity tests to determine the effects of water hardness on fluoride toxicity to Rainbow Trout. The 96-h LC50 for Rainbow Trout increased from 51 mg/L F^- at a hardness of 17 mg/L as $CaCO_3$ to an LC50 of 140 mg/L F- at a water hardness of 182 mg/L as $CaCO_3$. The authors developed an equation for this fluoride-hardness relationship that is the basis of the BCMOE (1995) WQG.

Smith et al. (1985) conducted static acute toxicity tests with Threespine Stickleback (*Gasterosteus aculeatus)* and Fathead Minnow at different water hardness concentrations. For Threespine Stickleback, the 96-h LC50s increased from 340 mg/L F^- at a hardness of 78 mg/L as $CaCO_3$ to 460 mg/L F- at a hardness of 300 mg/L as $CaCO_3$. Conversely, the 96-h LC50s for Fathead Minnow decreased from 315 mg/L F^- at hardness concentrations of 20 to 48 mg/L as $CaCO_3$ to 205 mg/L F^- at a hardness of 256 mg/L as $CaCO_3$.

Keller and Augspurger (2005) conducted 96-h toxicity tests with juveniles of the unionid Pheasantshell mussel, *Actinonaias pectorosa*. Tests were conducted at 25°C, at four water hardness concentrations ranging from 28 to 84 mg/L as $CaCO_3$. The 96-h LC50s ranged from 178 to 347 mg/L F^-; they generally increased (i.e., toxicity decreased) with increasing water hardness.

Banack et al. (2012) conducted toxicity tests with Rainbow Trout fry, Fathead Minnow, *C. dubia*, and *H. azteca*, to determine whether chloride concentrations of 2, 6, or 18 mg/L Cl^- affected fluoride toxicity. The toxicity of fluoride to Rainbow Trout fry and *H. azteca* decreased as the chloride concentration increased, but chloride did not affect the toxicity of fluoride to Fathead Minnow. Increasing the chloride concentration resulted in an increase in fluoride toxicity to *C. dubia*.

In summary, the above tests indicate that fluoride toxicity increases with increasing temperature. Thus, many of the benchmarks used for the CEB are likely conservative as they were derived at higher temperatures than would occur in Snap Lake. Fluoride toxicity also increases with water hardness. Again, benchmarks used in the CEB at lower hardness concentrations than Snap Lake are likely conservative. In contrast, increasing chloride concentrations did not reduce fluoride toxicity for all tested biota; thus, inclusion of benchmarks derived at variable chloride concentrations in the CEB is appropriate.

5 PROPOSED CHRONIC EFFECTS BENCHMARK FOR FLUORIDE

5.1 Overview of Benchmark Calculation Methodology

Toxicity test endpoints calculated from chronic studies were compiled using an SSD approach; no-effect and low-effect endpoints were given preference. When more than one endpoint was available from a particular study, only the most suitable, lowest endpoint was used in accordance with the CCME (2007) ranking system. For example, if both an EC10 and EC20 were reported for an endpoint then the EC10 was selected, and if both lethal and sublethal effects were assessed then only the more sensitive sublethal endpoint was selected. If endpoints from multiple studies were available for a particular species (see Sections 4.1 to 4.3), then with one exception[2] a Species Mean Chronic Value (SMCV) was calculated as the geometric mean of the most suitable endpoint from each study. The geometric mean, as opposed to the arithmetic mean, was used to minimize bias toward high test results. The resulting SMCV was used in the SSD so that there was only one data entry for each available species. SMCVs were then ranked from lowest to highest, and the percent of species affected was calculated using the following equation:

$$\text{Percent Affected} = (X - 0.5) / N$$

where X is the species rank, with 1 being the most sensitive species, and N is the total number of species in the database. The correction factor of 0.5 was used (Hazen plotting position [Aldenberg et al. 2002]) to create symmetry in cumulative probability (i.e., median ranked species will be associated with 50% affected) and to acknowledge that the concentration affecting the highest ranked species is not necessarily associated with adverse effects to the entire aquatic community.

SigmaPlot software was used to fit the SMCV data to a curve for the SSD, using a Weibull four-parameter model and log-transformed concentration data. The CCME (2007) approach for WQG derivation is to use the intercept of the fifth (5th) percentile of the SSD as the WQG, with the intent that this hazardous concentration to 5% of species (HC5) will provide protection to 95% of the aquatic species. This approach was adopted to calculate the fluoride CEB for Snap Lake.

5.2 Calculation of Fluoride CEB

Table 1 summarizes the toxicity test endpoints that were used to generate the SSD for fluoride. Data from 11 chronic studies with 15 species (representing 3 fish, 8 invertebrates, and 4 algae/plant species) were used for this calculation.

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[2] Two Rainbow Trout chronic studies were identified for inclusion in the SSD: a 21-d LC10 for survival of 4.8 mg/L F^- conducted with yearling fish (Herbert and Shurben 1964); and, a 34-d LC50 of 76 mg/L F^- conducted with embryos (Neuhold and Sigler 1960). Other testing with different life stages by Neuhold and Sigler (1960) showed that Rainbow Trout eggs and embryos were considerably less sensitive to fluoride than were older fish, presumably because they were not actively feeding until yolk sac absorption. Given the difference in sensitivities between the different life stages used in these two studies, only the Herbert and Shurben (1964) result was used in the SSD rather than calculating a SMCV.

Table 1: Chronic Toxicity Data Used to Generate Species Sensitivity Distribution (SSD) for Fluoride

Citation	Test Species	Common Name	Endpoint	Concentration [mg/L F]	Species Mean Chronic Value (SMCV)	Rank	Percent Affected
Sparks and Sandusky 1983	*Musculium transversum*	Fingernail clam	MATC	2.25	2.25	1	3%
Banack et al. 2012	*Hyalella azteca*	Amphipod	IC25	2.8	2.8	2	10%
Herbert and Shurben 1964	*Oncorhynchus mykiss*	Rainbow Trout	LC10	4.8	4.8	3	17%
Alonso and Camargo 2011	*Potamopyrgus antipodarum*	New Zealand mud snail	MATC	6.6	6.6	4	23%
Shi et al. 2009	*Acipenser baerii*	Siberian Sturgeon	IC10	7.7	7.7	5	30%
Del Piero et al. 2012	*Dreissena polymorpha*	Zebra Mussel	LC50	10.0	10	6	37%
Banack et al. 2012	*Ceriodaphnia dubia*	Water Flea	IC25	11.2	11.2	7	43%
Banack et al. 2012	*Chironomus dilutus*	Midge	IC25	11.5	11.5	8	50%
Fieser et al. 1986	*Daphnia magna*	Water Flea	IC10	27.7	27.7	9	57%
Hekman and Budd 1984	*Synechococcus leopoliensis*	Algae	EC13	50	50	10	63%
Metcalfe-Smith et al. 2003	*Pimephales promelas*	Fathead Minnow	IC25	72	67.4	11	70%
Banack et al. 2012	*Pimephales promelas*	Fathead Minnow	IC25	63.1			
Keller and Augspurger 2005	*Alasmidonta raveneliana*	Appalachian Elktoe	IC10	91	91	12	77%
Rai et al. 1998	*Chlorella vulgaris*	Algae	IC11	95	95	13	83%
Banack et al. 2012	*Pseudokirchneriella subcapitata*	Algae	IC25	217	217	14	90%
Banack et al. 2012	*Lemna minor*	Duckweed	IC25	229	229	15	97%

ECx = concentration of sample estimated to cause a specified effect to x% of the test organisms.

LCx = concentration of sample estimated to be lethal to x% of the test organisms.

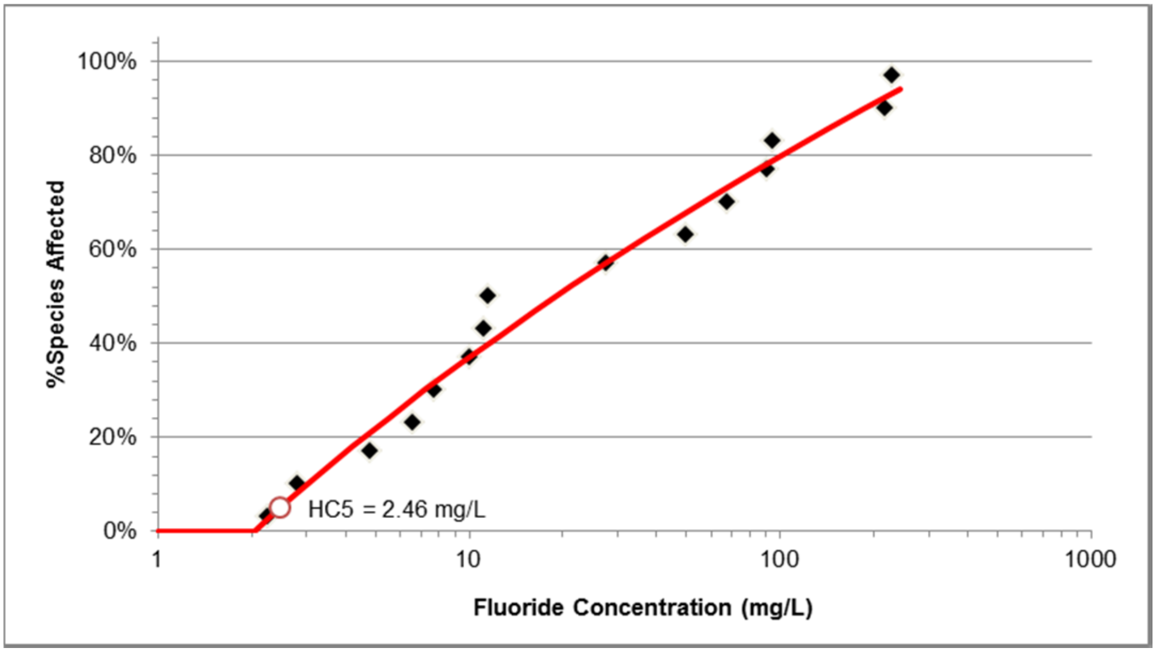
ICx = the inhibiting concentration for an x% effect; it is the concentration of sample estimated to cause x% reduction in growth or fecundity of the test organisms.

MATC = maximum acceptable toxicant concentration; the geometric mean of the NOEC and LOEC.

TDS = total dissolved solids; mg/L F = milligrams per litre fluoride;% = percent.

Figure 4 shows the SSD curve for the fluoride CEB dataset, and the associated HC5 of 2.46 mg/L F^-. That HC5 is within a factor of two of a benchmark of 1.47 mg/L F^- obtained by applying the BCMOE (1995) hardness-dependent WQG equation using the current Snap Lake water hardness of 140 mg/L as $CaCO_3$. However, the BCMOE (1995) WQG was derived from a single study that used acute data for Rainbow Trout at different hardness concentrations rather than the SSD approach; thus, the BC WQG is not as robust as the CEB calculated herein using multiple chronic studies and applying the CCME SSD approach. Accordingly, the CEB derived herein (2.46 mg/L F^-) is recommended as a site-specific water quality objective (SSWQO) for fluoride in Snap Lake.

Figure 4: Species Sensitivity Distribution for Fluoride



mg/L = milligrams per litre;% = percent.

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APPENDIX A

FLUORIDE TOXICITY DATA

Trophic Group	Common Name	Test Species	Life Stage	Temperature [°C]	Hardness [mg/L CaCO$_3$]	Exposure System	Test Duration	Biological Measurement	Endpoint	Concentration [mg/L F]	Citation
Acute Toxicity Tests											
Fish	Brown Trout	*Salmo trutta*	<8-week old fry; 2 cm	12	73	SR, M	100 h	Survival	LC50	15	Wright 1977
Fish	Brown Trout	*Salmo trutta fario*	fingerlings; 2 mo old	16.1	21.2	S, M	5 d	Survival	LC50	135.6	Camargo and Tarazona 1991
Fish	Brown Trout	*Salmo trutta fario*	fingerlings; 2 mo old	16.1	21.2	S, M	6 d	Survival	LC50	118.5	Camargo and Tarazona 1991
Fish	Brown Trout	*Salmo trutta fario*	fingerlings; 2 mo old	16.1	21.2	S, M	7 d	Survival	LC50	105.1	Camargo and Tarazona 1991
Fish	Brown Trout	*Salmo trutta fario*	fingerlings; 2 mo old	16.1	21.2	S, M	8 d	Survival	LC50	97.5	Camargo and Tarazona 1991
Fish	Chinese Sturgeon	*Acipenser sinensis*	larval; <1-d post-hatch	18 ± 0.2	22 ± 4	SR, N	6 d	Survival	LC50	131.7	Zhuang et al. 2011
Fish	Chinook Salmon	*Oncorhynchus tshawytscha*	adult	11 - 12	NR	FT, NR	0.5 h	Avoidance	LOEC	0.2	Damkaer and Dey 1989
Fish	Chinook Salmon	*Oncorhynchus tshawytscha*	adult	11 - 12	NR	FT, NR	0.5 h	Avoidance	LOEC	0.5	Damkaer and Dey 1989
Fish	Chum Salmon	*Oncorhynchus keta*	adult	11 - 12	NR	FT, NR	0.5 h	Avoidance	LOEC	0.5	Damkaer and Dey 1989
Fish	Coho Salmon	*Oncorhynchus kisutch*	adult	11 - 12	NR	FT, NR	0.5 h	Avoidance	LOEC	0.2	Damkaer and Dey 1989
Fish	Coho Salmon	*Oncorhynchus kisutch*	adult	11 - 12	NR	FT, NR	0.5 h	Avoidance	LOEC	0.5	Damkaer and Dey 1989
Fish	Fathead Minnow	*Pimephales promelas*	juvenile (10 d old)	20	140-150	SR, NR	4 d	Survival	LC50	262	Metcalfe-Smith et al. 2003
Fish	Fathead Minnow	*Pimephales promelas*	<1 g	20	92	S, M	4 d	Survival	LC50	180	Smith et al. 1985
Fish	Fathead Minnow	*Pimephales promelas*	<1 g	20	256	S, M	4 d	Survival	LC50	205	Smith et al. 1985
Fish	Fathead Minnow	*Pimephales promelas*	<1 g	15-19	10-44	S, M	4 d	Survival	LC50	315	Smith et al. 1985
Fish	Fathead Minnow	*Pimephales promelas*	<1 g	16-20	20-48	S, M	4 d	Survival	LC50	315	Smith et al. 1985
Fish	Indian Carp	*Catla catla*	eggs	37	NR	S, M	8 h	Hatching time	NOEC	1.86	Pillai and Mane 1984
Fish	Indian Carp	*Catla catla*	eggs	37	NR	S, M	8 h	Hatching time	LOEC	3.56	Pillai and Mane 1984
Fish	Indian Carp	*Catla catla*	eggs	37	NR	S, M	8 h	Egg weight	NOEC	3.56	Pillai and Mane 1984
Fish	Indian Carp	*Catla catla*	eggs	37	NR	S, M	8 h	Egg weight	LOEC	7.34	Pillai and Mane 1984
Fish	Mosquitofish	*Gambusia affinis*	Adult	21-24	NR	NR	4 d	Survival	LC50	418	Wallen et al. 1957 (cited from Environment Canada 2001)
Fish	Pool Barb	*Puntius sophore*	juveniles	17.9-18.6	284-302	SR, NR	96 h	Mortality	LC50	56.7	Narwaria and Saksena 2012
Fish	Rainbow Trout	*Oncorhynchus mykiss*	59 mm, 1.8 g	12	17	S, M	4 d	Survival	LC50	51	Pimentel and Bulkley 1983
Fish	Rainbow Trout	*Oncorhynchus mykiss*	59 mm, 1.8 g	12	49	S, M	4 d	Survival	LC50	128	Pimentel and Bulkley 1983
Fish	Rainbow Trout	*Oncorhynchus mykiss*	59 mm, 1.8 g	12	182	S, M	4 d	Survival	LC50	140	Pimentel and Bulkley 1983
Fish	Rainbow Trout	*Oncorhynchus mykiss*	59 mm, 1.8 g	12	385	S, M	4 d	Survival	LC50	193	Pimentel and Bulkley 1983
Fish	Rainbow Trout	*Oncorhynchus mykiss*	<3 g	15	23-62	S, M	4 d	Survival	LC50	200	Smith et al. 1985
Fish	Rainbow Trout	*Oncorhynchus mykiss*	fingerlings; 2 mo old	15.3	22.4	S, M	8 d	Survival	LC50	64.1	Camargo and Tarazona 1991
Fish	Rainbow Trout	*Oncorhynchus mykiss*	fingerlings; 2 mo old	15.3	22.4	S, M	7 d	Survival	LC50	73.4	Camargo and Tarazona 1991
Fish	Rainbow Trout	*Oncorhynchus mykiss*	fingerlings; 2 mo old	15.3	22.4	S, M	6 d	Survival	LC50	85.1	Camargo and Tarazona 1991
Fish	Rainbow Trout	*Oncorhynchus mykiss*	fingerlings; 2 mo old	15.3	22.4	S, M	5 d	Survival	LC50	92.4	Camargo and Tarazona 1991
Fish	Rainbow Trout	*Oncorhynchus mykiss*	NR	NR	SOFT	NR	NR	NR	NR	358	Klein 1958 (cited from BCMOE 1995)
Fish	Threespine Stickleback	*Gasterosteus aculeatus*	<1 g	20	78	S, M	4 d	Survival	LC50	340	Smith et al. 1985
Fish	Threespine Stickleback	*Gasterosteus aculeatus*	<1 g	20	146	S, M	4 d	Survival	LC50	380	Smith et al. 1985
Fish	Threespine Stickleback	*Gasterosteus aculeatus*	<1 g	20	300	S, M	4 d	Survival	LC50	460	Smith et al. 1985
Invertebrate	Amphipod	*Hyalella azteca*	1 - 7 d old	20	140-150	S, NR	2 d	Survival	LC50	32.3	Metcalfe-Smith et al. 2003
Invertebrate	Amphipod	*Hyalella azteca*	14 days	22	68-100	S, M	2 d	Survival	LC50	16.0	USEPA 2010
Invertebrate	Amphipod	*Hyalella azteca*	14 days	22	68-100	S, M	4 d	Survival	LC50	13.4	USEPA 2010
Invertebrate	Appalachian Elktoe	*Alasmidonta raveneliana*	glochidia	25	30	S, M	1 d	Survival	LC50	288	Keller and Augspurger 2005

Trophic Group	Common Name	Test Species	Life Stage	Temperature [°C]	Hardness [mg/L $CaCO_3$]	Exposure System	Test Duration	Biological Measurement	Endpoint	Concentration [mg/L F]	Citation
Invertebrate	Appalachian Elktoe	*Alasmidonta raveneliana*	juvenile	25	28	S, M	4 d	Survival	NOEC	250	Keller and Augspurger 2005
Invertebrate	Appalachian Elktoe	*Alasmidonta raveneliana*	juvenile	25	28	S, M	4 d	Survival	LC50	303	Keller and Augspurger 2005
Invertebrate	Caddisfly	*Hydropsyche bulbifera*	Last instar larvae	15.2	15.6		3 d	Survival	LC50	44.9	Camargo 1991
Invertebrate	Caddisfly	*Hydropsyche bulbifera*	Last instar larvae	15.2	15.6		2 d	Survival	LC50	79.2	Camargo 1991
Invertebrate	Caddisfly	*Hydropsyche exocellata*	Last instar larvae	15.2	15.6		3 d	Survival	LC50	43.7	Camargo 1991
Invertebrate	Caddisfly	*Hydropsyche exocellata*	Last instar larvae	15.2	15.6		2 d	Survival	LC50	86.6	Camargo 1991
Invertebrate	Caddisfly	*Hydropsyche lobata*	Last instar larvae	15.2	15.6		3 d	Survival	LC50	78.2	Camargo 1991
Invertebrate	Caddisfly	*Chimarra marginata*	Last instar larvae	15.2	15.6		3 d	Survival	LC50	79.7	Camargo 1991
Invertebrate	Caddisfly	*Chimarra marginata*	Last instar larvae	15.2	15.6		2 d	Survival	LC50	120.0	Camargo 1991
Invertebrate	Caddisfly	*Hydropsyche pellucidula*	Last instar larvae	15.2	15.6		2.5 d	Survival	LC50	72.0	Camargo 1991
Invertebrate	Caddisfly	*Hydropsyche pellucidula*	Last instar larvae	15.2	15.6		2 d	Survival	LC50	112.0	Camargo 1991
Invertebrate	Caddisfly	*Hydropsyche tibialis*	middle instar larvae	17.8	19.5	S, N	5 d	Survival	LC50	71.8	Camargo 2004
Invertebrate	Caddisfly	*Hydropsyche tibialis*	middle instar larvae	17.8	19.5	S, N	5 d	Survival	NOEC	15	Camargo 2004
Invertebrate	Caddisfly	*Hydropsyche tibialis*	middle instar larvae	17.8	19.5	S, N	5 d	Survival	LC50	28	Camargo 2004
Invertebrate	Caddisfly	*Hydropsyche tibialis*	middle instar larvae	17.8	19.5	S, N	5 d	Survival	NOEC	5	Camargo 2004
Invertebrate	Caddisfly	*Hydropsyche tibialis*	Last instar larvae	17.8	19.5	S, N	5 d	Survival	LC50	76	Camargo 2004
Invertebrate	Caddisfly	*Hydropsyche tibialis*	Last instar larvae	17.8	19.5	S, N	5 d	Survival	NOEC	15	Camargo 2004
Invertebrate	Caddisfly	*Hydropsyche tibialis*	Last instar larvae	17.8	19.5	S, N	5 d	Survival	LC50	37	Camargo 2004
Invertebrate	Caddisfly	*Hydropsyche tibialis*	Last instar larvae	17.8	19.5	S, N	5 d	Survival	NOEC	10	Camargo 2004
Invertebrate	Caddisfly	*Chimarra marginata*	Last instar larvae	15.2	15.6		4 d	Migration	NOEC	12.4	Camargo and La Point 1995
Invertebrate	Caddisfly	*Chimarra marginata*	Last instar larvae	15.2	15.6		4 d	Migration	LOEC	19.4	Camargo and La Point 1995
Invertebrate	Caddisfly	*Chimarra marginata*	Last instar larvae	15.2	15.6		4 d	Migration	MATC	15.5	Camargo and La Point 1995
Invertebrate	Caddisfly	*Chimarra marginata*	Last instar larvae	15.2	15.6		4 d	Migration	EC50	38.3	Camargo and La Point 1995
Invertebrate	Caddisfly	*Hydropsyche bulbifera*	Last instar larvae	15.2	15.6		4 d	Migration	NOEC	2.5	Camargo and La Point 1995
Invertebrate	Caddisfly	*Hydropsyche bulbifera*	Last instar larvae	15.2	15.6		4 d	Migration	MATC	7.6	Camargo and La Point 1995
Invertebrate	Caddisfly	*Hydropsyche bulbifera*	Last instar larvae	15.2	15.6		4 d	Migration	MATC	4.4	Camargo and La Point 1995
Invertebrate	Caddisfly	*Hydropsyche bulbifera*	Last instar larvae	15.2	15.6		4 d	Migration	EC50	23.0	Camargo and La Point 1995
Invertebrate	Caddisfly	*Hydropsyche exocellata*	Last instar larvae	15.2	15.6		4 d	Migration	EC50	24.97	Camargo and La Point 1995
Invertebrate	Caddisfly	*Hydropsyche exocellata*	Last instar larvae	15.2	15.6		1 d	Migration	NOEC	30.08	Camargo and La Point 1995
Invertebrate	Caddisfly	*Hydropsyche lobata*	Last instar larvae	15.2	15.6		4 d	Migration	NOEC	12.2	Camargo and La Point 1995
Invertebrate	Caddisfly	*Hydropsyche lobata*	Last instar larvae	15.2	15.6		4 d	Migration	LOEC	19.1	Camargo and La Point 1995
Invertebrate	Caddisfly	*Hydropsyche lobata*	Last instar larvae	15.2	15.6		4 d	Migration	MATC	15.3	Camargo and La Point 1995
Invertebrate	Caddisfly	*Hydropsyche lobata*	Last instar larvae	15.2	15.6		4 d	Migration	EC50	29.0	Camargo and La Point 1995
Invertebrate	Caddisfly	*Hydropsyche pellucidulla*	Last instar larvae	15.2	15.6		4 d	Migration	NOEC	2.5	Camargo and La Point 1995
Invertebrate	Caddisfly	*Hydropsyche pellucidulla*	Last instar larvae	15.2	15.6		4 d	Migration	LOEC	7.6	Camargo and La Point 1995
Invertebrate	Caddisfly	*Hydropsyche pellucidulla*	Last instar larvae	15.2	15.6		4 d	Migration	MATC	4.4	Camargo and La Point 1995
Invertebrate	Caddisfly	*Hydropsyche pellucidulla*	Last instar larvae	15.2	15.6		4 d	Migration	EC50	29.0	Camargo and La Point 1995
Invertebrate	Caddisfly	*Chimarra marginata*	Last instar larvae	17.3	12.04	S, M	4 d	Survival	LC50	44.9	Camargo and Tarazona 1990
Invertebrate	Caddisfly	*Chimarra marginata*	Last instar larvae	17.3	12.04	S, M	4 d	Survival	LC10	19.4	Camargo and Tarazona 1990
Invertebrate	Caddisfly	*Chimarra marginata*	Last instar larvae	15.95	13.18	S, M	4 d	Survival	LC20	20.5	Camargo and Tarazona 1990
Invertebrate	Caddisfly	*Hydropsyche bulbifera*	Last instar larvae	15.15	17.6	S, M	4 d	Survival	LC50	26.3	Camargo and Tarazona 1990

Trophic Group	Common Name	Test Species	Life Stage	Temperature [°C]	Hardness [mg/L $CaCO_3$]	Exposure System	Test Duration	Biological Measurement	Endpoint	Concentration [mg/L F]	Citation
Invertebrate	Caddisfly	*Hydropsyche bulbifera*	Last instar larvae	15.15	17.6	S, M	4 d	Survival	LC10	7.4	Camargo and Tarazona 1990
Invertebrate	Caddisfly	*Hydropsyche bulbifera*	Last instar larvae	13.25	16.28	S, M	4 d	Survival	LC10	11.8	Camargo and Tarazona 1990
Invertebrate	Caddisfly	*Hydropsyche exocellata*	Last instar larvae	17.3	12.04	S, M	4 d	Survival	LC50	26.5	Camargo and Tarazona 1990
Invertebrate	Caddisfly	*Hydropsyche exocellata*	Last instar larvae	17.3	12.04	S, M	4 d	Survival	LC10	19.4	Camargo and Tarazona 1990
Invertebrate	Caddisfly	*Hydropsyche exocellata*	Last instar larvae	15.95	13.18	S, M	4 d	Survival	LC20	20.5	Camargo and Tarazona 1990
Invertebrate	Caddisfly	*Hydropsyche lobata*	Last instar larvae	14.1	18.77	S, M	4 d	Survival	LC50	48.2	Camargo and Tarazona 1990
Invertebrate	Caddisfly	*Hydropsyche lobata*	Last instar larvae	14.1	18.77	S, M	4 d	Survival	LC10	19.1	Camargo and Tarazona 1990
Invertebrate	Caddisfly	*Hydropsyche lobata*	Last instar larvae	13.25	16.28	S, M	4 d	Survival	LC10	18.9	Camargo and Tarazona 1990
Invertebrate	Caddisfly	*Hydropsyche pellucidula*	Last instar larvae	15.15	17.6		4 d	Survival	LC50	38.5	Camargo and Tarazona 1990
Invertebrate	Caddisfly	*Hydropsyche pellucidula*	Last instar larvae	15.15	17.6		4 d	Survival	LC17	21.3	Camargo and Tarazona 1990
Invertebrate	Caddisfly	*Hydropsyche pellucidula*	Last instar larvae	14.1	18.77		4 d	Survival	LC20	19.1	Camargo and Tarazona 1990
Invertebrate	Caddisfly	*Cheumatopsyche pettiti*	Last instar larvae	18	40.2	S, M	2 d	Survival	LC50	128	Camargo et al. 1992a
Invertebrate	Caddisfly	*Cheumatopsyche pettiti*	Last instar larvae	18	40.2	S, M	3 d	Survival	LC50	73	Camargo et al. 1992a
Invertebrate	Caddisfly	*Cheumatopsyche pettiti*	Last instar larvae	18	40.2	S, M	4 d	Survival	LC50	43	Camargo et al. 1992a
Invertebrate	Caddisfly	*Cheumatopsyche pettiti*	Last instar larvae	18	40.2	S, M	5 d	Survival	LC50	32	Camargo et al. 1992a
Invertebrate	Caddisfly	*Cheumatopsyche pettiti*	Last instar larvae	18	40.2	S, M	6 d	Survival	LC50	24	Camargo et al. 1992a
Invertebrate	Caddisfly	*Cheumatopsyche pettiti*	Last instar larvae	18	40.2	S, M	6 d	Survival	LC10	12	Camargo et al. 1992a
Invertebrate	Caddisfly	*Hydropsyche bronta*	Last instar larvae	18	40.2	S, M	2 d	Survival	LC50	53	Camargo et al. 1992a
Invertebrate	Caddisfly	*Hydropsyche bronta*	Last instar larvae	18	40.2	S, M	3 d	Survival	LC50	26	Camargo et al. 1992a
Invertebrate	Caddisfly	*Hydropsyche bronta*	Last instar larvae	18	40.2	S, M	4 d	Survival	LC50	17	Camargo et al. 1992a
Invertebrate	Caddisfly	*Hydropsyche bronta*	Last instar larvae	18	40.2	S, M	5 d	Survival	LC50	13	Camargo et al. 1992a
Invertebrate	Caddisfly	*Hydropsyche bronta*	Last instar larvae	18	40.2	S, M	6 d	Survival	LC50	12	Camargo et al. 1992a
Invertebrate	Caddisfly	*Hydropsyche bronta*	Last instar larvae	18	40.2	S, M	6 d	Survival	LC20	6.0	Camargo et al. 1992a
Invertebrate	Caddisfly	*Hydropsyche occidentalis*	Last instar larvae	18	40.2	S, M	2 d	Survival	LC50	102	Camargo et al. 1992a
Invertebrate	Caddisfly	*Hydropsyche occidentalis*	Last instar larvae	18	40.2	S, M	3 d	Survival	LC50	54	Camargo et al. 1992a
Invertebrate	Caddisfly	*Hydropsyche occidentalis*	Last instar larvae	18	40.2	S, M	4 d	Survival	LC50	35	Camargo et al. 1992a
Invertebrate	Caddisfly	*Hydropsyche occidentalis*	Last instar larvae	18	40.2	S, M	5 d	Survival	LC50	27	Camargo et al. 1992a
Invertebrate	Caddisfly	*Hydropsyche occidentalis*	Last instar larvae	18	40.2	S, M	6 d	Survival	LC50	21	Camargo et al. 1992a
Invertebrate	Caddisfly	*Hydropsyche occidentalis*	Last instar larvae	18	40.2	S, M	6 d	Survival	LC20	10	Camargo et al. 1992a
Invertebrate	Caddisfly	*Chimarra marginata*	Last instar larvae	15.2	15.6	S, M	4 d	Migration	EC50	33.5	Camargo et al. 1992b
Invertebrate	Caddisfly	*Chimarra marginata*	Last instar larvae	15.2	15.6	S, M	4 d	Abdomen	EC50	109	Camargo et al. 1992b
Invertebrate	Caddisfly	*Hydropsyche bulbifera*	Last instar larvae	15.2	15.6	S, M	4 d	Abdomen	NOEC	2.51	Camargo et al. 1992b
Invertebrate	Caddisfly	*Hydropsyche bulbifera*	Last instar larvae	15.2	15.6	S, M	4 d	Abdomen	EC50	18.9	Camargo et al. 1992b
Invertebrate	Caddisfly	*Hydropsyche bulbifera*	Last instar larvae	15.2	15.6	S, M	4 d	Migration	EC50	19.2	Camargo et al. 1992b
Invertebrate	Caddisfly	*Hydropsyche exocellata*	Last instar larvae	15.2	15.6	S, M	4 d	Migration	EC50	21.3	Camargo et al. 1992b
Invertebrate	Caddisfly	*Hydropsyche exocellata*	Last instar larvae	15.2	15.6	S, M	4 d	Abdomen	EC50	20.5	Camargo et al. 1992b
Invertebrate	Caddisfly	*Hydropsyche lobata*	Last instar larvae	15.2	15.6	S, M	4 d	Migration	EC50	34.8	Camargo et al. 1992b
Invertebrate	Caddisfly	*Hydropsyche lobata*	Last instar larvae	15.2	15.6	S, M	4 d	Abdomen	EC50	33.9	Camargo et al. 1992b
Invertebrate	Caddisfly	*Hydropsyche pellucidulla*	Last instar larvae	15.2	15.6	S, M	4 d	Abdomen	NOEC	2.51	Camargo et al. 1992b
Invertebrate	Caddisfly	*Hydropsyche pellucidulla*	Last instar larvae	15.2	15.6	S, M	4 d	Abdomen	EC50	23.5	Camargo et al. 1992b
Invertebrate	Caddisfly	*Hydropsyche pellucidulla*	Last instar larvae	15.2	15.6	S, M	4 d	Migration	EC50	24.6	Camargo et al. 1992b

Trophic Group	Common Name	Test Species	Life Stage	Temperature [°C]	Hardness [mg/L $CaCO_3$]	Exposure System	Test Duration	Biological Measurement	Endpoint	Concentration [mg/L F]	Citation
Invertebrate	Grooved fingernail clam	*Sphaerium simile*	juvenile	22	2 to 160	S, M	2 d	Survival	LC50	>800	USEPA 2010
Invertebrate	Grooved fingernail clam	*Sphaerium simile*	juvenile	22	2 to 160	S, M	4 d	Survival	LC50	62	USEPA 2010
Invertebrate	Mayfly	*Hexagenia limbata*	larvae (3-4 months)	20	140-150	S, NR	4 d	Survival	LC50	283	Metcalfe-Smith et al. 2003
Invertebrate	Midge	*Chironomus tentans*	larvae (10 d old)	20	140-150	S, NR	4 d	Survival	LC50	14.6	Metcalfe-Smith et al. 2003
Invertebrate	New Zealand mud snail	*Potamopyrgus antipodarum*	Juvenile (1.2 mm)	15.6 ± 0.5	92.5 ± 5.4	SR, M	4 d	Survival	LC50	52.2	Aguirre-Sierra et al. 2011
Invertebrate	New Zealand mud snail	*Potamopyrgus antipodarum*	Juvenile (1.2 mm)	15.6 ± 0.6	92.5 ± 5.5	SR, M	4 d	Immobilization	EC50	39.2	Aguirre-Sierra et al. 2011
Invertebrate	New Zealand mud snail	*Potamopyrgus antipodarum*	Adult (3.8 mm)	15.6 ± 0.7	92.5 ± 5.6	SR, M	4 d	Survival	LC50	69.9	Aguirre-Sierra et al. 2011
Invertebrate	New Zealand mud snail	*Potamopyrgus antipodarum*	Adult (3.8 mm)	15.6 ± 0.8	92.5 ± 5.7	SR, M	4 d	Immobilization	EC50	58.2	Aguirre-Sierra et al. 2011
Invertebrate	New Zealand mud snail	*Potamopyrgus antipodarum*	NR	12.6 ± 0.65	91.3 ± 6.6	S, M	4 d	Survival	LC50	58.5	Alonso and Camargo 2011
Invertebrate	New Zealand mud snail	*Potamopyrgus antipodarum*	NR	12.6 ± 0.65	91.3 ± 6.6	S, M	4 d	Immobilization	EC50	47.0	Alonso and Camargo 2011
Invertebrate	Paper Pondshell	*Utterbackia imbecillis*	juvenile	25	34	S, M	4 d	Survival	LC50	234	Keller and Augspurger 2005
Invertebrate	Paper Pondshell	*Utterbackia imbecillis*	glochidia	25	30	S, M	1 d	Survival	LC50	351	Keller and Augspurger 2005
Invertebrate	Pheasantshell, Mussel	*Actinonaias pectorosa*	juvenile	25	30	S, M	4 d	Survival	LC50	178	Keller and Augspurger 2005
Invertebrate	Pheasantshell, Mussel	*Actinonaias pectorosa*	juvenile	25	28	S, M	4 d	Survival	LC50	259	Keller and Augspurger 2005
Invertebrate	Pheasantshell, Mussel	*Actinonaias pectorosa*	juvenile	25	84	S, M	4 d	Survival	LC50	298	Keller and Augspurger 2005
Invertebrate	Pheasantshell, Mussel	*Actinonaias pectorosa*	juvenile	25	68	S, M	4 d	Survival	LC50	347	Keller and Augspurger 2005
Invertebrate	Tubificid worm	*Branchiura sowerbyi*	NR	17 ± 0.5	NR	S, N	4 d	Survival	LC50	267.6	Casellato et al. 2013
Invertebrate	Tubificid worm	*Branchiura sowerbyi*	NR	22± 0.5	NR	S, N	4 d	Survival	LC50	91.3	Casellato et al. 2013
Invertebrate	Tubificid worm	*Branchiura sowerbyi*	NR	17 ± 0.5	NR	S, N	4 d	Survival	LC50	80.1	Casellato et al. 2013
Invertebrate	Tubificid worm	*Branchiura sowerbyi*	NR	22 ± 0.5	NR	S, N	4 d	Survival	LC50	61.7	Casellato et al. 2013
Invertebrate	Water Flea	*Daphnia magna*	Neonates (<24 h)	20	250	S, N	2 d	Immobilization	EC50	98	Dave 1984
Invertebrate	Water Flea	*Daphnia magna*	Neonates (<24 h)	25	169.3	S, M	2 d	Survival	LC50	180	Fieser et al. 1986
Invertebrate	Water Flea	*Daphnia magna*	Neonates (<24 h)	20	169.3	S, M	2 d	Survival	LC50	247	Fieser et al. 1986
Invertebrate	Water Flea	*Daphnia magna*	Neonates (<24 h)	15	169.3	S, M	2 d	Survival	LC50	350	Fieser et al. 1986
Invertebrate	Water Flea	*Daphnia magna*	<24h of age	22	173	S, N	2 d	Survival	LC50	154	LeBlanc 1980
Invertebrate	Water Flea	*Daphnia magna*	NR (Env Can protocol)	20	140-150	S, NR	2 d	Survival	LC50	124.1	Metcalfe-Smith et al. 2003
Invertebrate	Wavy-Rayed Lampmussel	*Lampsilis fasciola*	juvenile	25	32	S, M	4 d	Survival	LC50	172	Keller and Augspurger 2005
Invertebrate	Zebra Mussel	*Dreissena polymorpha*	Adult (1.5 - 2 cm)	17 ± 0.5	106 ± 14	S, NR	4 d	Survival	LC50	361	Del Piero et al. 2012
Invertebrate	Zebra Mussel	*Dreissena polymorpha*	Adult (1.5 - 2 cm)	22 ± 0.5	106 ± 14	S, NR	4 d	Survival	LC50	62	Del Piero et al. 2012
Chronic and Sub-chronic Toxicity Tests											
Fish	Common Carp	*Cyprinus carpio*	Juvenile	22-24	20	SR, M	90 d	reduced enzyme activity in gill tissue	NOEC	63.3	Cao et al. 2013
Fish	Common Carp	*Cyprinus carpio*	Juvenile	22-24	20	SR, M	90 d	reduced enzyme activity in gill tissue	LOEC	77.7	Cao et al. 2013
Fish	Common Carp	*Cyprinus carpio*	Juvenile	22-24	20	SR, M	90 d	reduced enzyme activity in gill tissue	MATC	70.1	Cao et al. 2013
Fish	Fathead Minnow	*Pimephales promelas*	<24h post-hatch	25	90	SR, NR	7 d	Growth	IC25	82.2	Banack et al. 2012
Fish	Fathead Minnow	*Pimephales promelas*	<24h post-hatch	25	86	SR, NR	7 d	Growth	IC25	63.1	Banack et al. 2012

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Fish	Fathead Minnow	*Pimephales promelas*	<24h post-hatch	25	86	SR, NR	7 d	Growth	IC25	93.2	Banack et al. 2012
Fish	Fathead Minnow	*Pimephales promelas*	<24h post-hatch	25	280	SR, NR	7 d	Growth	IC25	94	Metcalfe-Smith et al. 2003
Fish	Fathead Minnow	*Pimephales promelas*	<24h post-hatch	25	280	SR, NR	7 d	Survival	LC25	145	Metcalfe-Smith et al. 2003
Fish	Fathead Minnow	*Pimephales promelas*	<24h post-hatch	25	160	SR, NR	7 d	Growth	IC25	72	Metcalfe-Smith et al. 2003
Fish	Fathead Minnow	*Pimephales promelas*	<24h post-hatch	25	160	SR, NR	7 d	Survival	LC25	132	Metcalfe-Smith et al. 2003
Fish	Rainbow Trout	*Oncorhynchus mykiss*	yearlings; 10 cm	14.5	12	SR, N	21 d	Survival	LC5	4	Herbert and Shurben 1964
Fish	Rainbow Trout	*Oncorhynchus mykiss*	yearlings; 10 cm	14.5	12	SR, N	21 d	Survival	LC10	5	Herbert and Shurben 1964
Fish	Rainbow Trout	*Oncorhynchus mykiss*	yearlings; 10 cm	14.5	12	SR, N	21 d	Survival	LC20	6	Herbert and Shurben 1964
Fish	Rainbow Trout	*Oncorhynchus mykiss*	yearlings; 10 cm	14.5	12	SR, N	21 d	Survival	LC50	8.5	Herbert and Shurben 1964
Fish	Rainbow Trout	*Oncorhynchus mykiss*	yearlings; 10 cm	14.5	45	SR, M	21 d	Survival	LC0	75	Herbert and Shurben 1964
Fish	Rainbow Trout	*Oncorhynchus mykiss*	yearlings; 10 cm	14.5	45	SR, M	21 d	Survival	LC100	113	Herbert and Shurben 1964
Fish	Rainbow Trout	*Oncorhynchus mykiss*	yearlings; 10 cm	14.5	320	SR, M	21 d	Survival	LC0	100	Herbert and Shurben 1964
Fish	Rainbow Trout	*Oncorhynchus mykiss*	yearlings; 10 cm	14.5	320	SR, M	21 d	Survival	LC100	200	Herbert and Shurben 1964
Fish	Rainbow Trout	*Oncorhynchus mykiss*	20-d old embryos	7.7	7.5	S, M	18 d	Survival	LC50	222 - 273	Neuhold and Sigler 1960
Fish	Rainbow Trout	*Oncorhynchus mykiss*	20-d old embryos	12.8	7.5	S, M	9 d	Survival	LC50	242 - 261	Neuhold and Sigler 1960
Fish	Rainbow Trout	*Oncorhynchus mykiss*	20-d old embryos	15.5	7.5	S, M	7 d	Survival	LC50	237 - 281	Neuhold and Sigler 1960
Fish	Rainbow Trout	*Oncorhynchus mykiss*	20-d old embryos	15.5	7.5	S, M	34 d	Survival	LC50	76	Neuhold and Sigler 1960
Fish	Siberian Sturgeon	*Acipenser baerii*	juvenile; 10.8 cm, 8.55 g	23	22	SR, M	90 d	Survival	LC0	>51.8	Shi et al. 2009
Fish	Siberian Sturgeon	*Acipenser baerii*	juvenile; 10.8 cm, 8.55 g	23	22	SR, M	90 d	Growth	NOEC	3.1	Shi et al. 2009
Fish	Siberian Sturgeon	*Acipenser baerii*	juvenile; 10.8 cm, 8.55 g	23	22	SR, M	90 d	Growth	LOEC	7.8	Shi et al. 2009
Fish	Siberian Sturgeon	*Acipenser baerii*	juvenile; 10.8 cm, 8.55 g	23	22	SR, M	90 d	Growth	MATC	4.9	Shi et al. 2009
Fish	Siberian Sturgeon	*Acipenser baerii*	juvenile; 10.8 cm, 8.55 g	23	22	SR, M	90 d	Growth	IC10	7.7	Shi et al. 2009
Fish	Siberian Sturgeon	*Acipenser baerii*	juvenile; 10.8 cm, 8.55 g	23	22	SR, M	90 d	Growth	IC20	>51.8	Shi et al. 2009
Invertebrate	Amphipod	*Hyalella azteca*	juvenile	23	90	NR	14 d	Growth	IC25	2.8	Banack et al. 2012
Invertebrate	Amphipod	*Hyalella azteca*	juvenile	23	88	NR	14 d	Growth	IC25	5.1	Banack et al. 2012
Invertebrate	Amphipod	*Hyalella azteca*	juvenile	23	88	NR	14 d	Growth	IC25	7.1	Banack et al. 2012
Invertebrate	Appalachian Elktoe	*Alasmidonta raveneliana*	juvenile	25	28	SR, M	9 d	Survival	LC50	223	Keller and Augspurger 2005
Invertebrate	Appalachian Elktoe	*Alasmidonta raveneliana*	juvenile	25	28	SR, M	9 d	Growth (shell length)	LOEC	31	Keller and Augspurger 2005
Invertebrate	Appalachian Elktoe	*Alasmidonta raveneliana*	juvenile	25	28	SR, M	9 d	Growth (shell length)	IC10	91	Keller and Augspurger 2005
Invertebrate	Fingernail clam	*Musculium transversum*	adult	20.9	232.4	FT, M	56 d	Survival	NOEC	1.80	Sparks and Sandusky 1983
Invertebrate	Fingernail clam	*Musculium transversum*	adult	20.9	232.4	FT, M	56 d	Survival	LOEC	2.82	Sparks and Sandusky 1983
Invertebrate	Fingernail clam	*Musculium transversum*	adult	20.9	232.4	FT, M	56 d	Survival	MATC	2.25	Sparks and Sandusky 1983
Invertebrate	Fingernail clam	*Musculium transversum*	adult	20.9	232.4	FT, M	56 d	Survival	LC50	>4.56	Sparks and Sandusky 1983
Invertebrate	Fingernail clam	*Musculium transversum*	adult	20.9	232.4	FT, M	56 d	Growth (shell length)	NOEC	4.56	Sparks and Sandusky 1983
Invertebrate	Midge	*Chironomus dilutus*	juvenile	23	90	NR	10 d	Growth	IC25	11.5	Banack et al. 2012
Invertebrate	New Zealand mud snail	*Potamopyrgus antipodarum*	3.6 mm shell length	12.2	96.8	SR, M	28 d	Reproduction - newborn production	NOEC	4.6	Alonso and Camargo 2011

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Invertebrate	New Zealand mud snail	*Potamopyrgus antipodarum*	3.6 mm shell length	12.2	96.8	SR, M	28 d	Reproduction - newborn production	LOEC	9.5	Alonso and Camargo 2011
Invertebrate	New Zealand mud snail	*Potamopyrgus antipodarum*	3.6 mm shell length	12.2	96.8	SR, M	28 d	Reproduction - newborn production	MATC	6.6	Alonso and Camargo 2011
Invertebrate	New Zealand mud snail	*Potamopyrgus antipodarum*	3.6 mm shell length	12.2	96.8	SR, M	28 d	Survival	NOEC	16.2	Alonso and Camargo 2011
Invertebrate	Tubificid worm	*Branchiura sowerbyi*	9 - 12 cm	23 ± 1	NR	SR, N	5 months	Gametogenesis	LOEC	6.8	Casellato et al. 2013
Invertebrate	Water Flea	*Ceriodaphnia dubia*	Neonates (<24 h)	25	82	SR, NR	7 d	Reproduction	IC25	17.2	Banack et al. 2012
Invertebrate	Water Flea	*Ceriodaphnia dubia*	Neonates (<24 h)	25	82	SR, NR	7 d	Reproduction	IC25	12.7	Banack et al. 2012
Invertebrate	Water Flea	*Ceriodaphnia dubia*	Neonates (<24 h)	25	88	SR, NR	7 d	Reproduction	IC25	11.2	Banack et al. 2012
Invertebrate	Water Flea	*Daphnia magna*	Neonates (<24 h)	19.5-21.5	250	SR, N	21 d	Survival	NOEC	3.7	Dave 1984
Invertebrate	Water Flea	*Daphnia magna*	Neonates (<24 h)	19.5-21.5	250	SR, N	21 d	Survival	LOEC	7.4	Dave 1984
Invertebrate	Water Flea	*Daphnia magna*	Neonates (<24 h)	19.5-21.5	250	SR, N	21 d	Survival	MATC	5.2	Dave 1984
Invertebrate	Water Flea	*Daphnia magna*	Neonates (<24 h)	19.5-21.5	250	SR, N	21 d	Body length	NOEC	3.7	Dave 1984
Invertebrate	Water Flea	*Daphnia magna*	Neonates (<24 h)	19.5-21.5	250	SR, N	21 d	Body length	LOEC	7.4	Dave 1984
Invertebrate	Water Flea	*Daphnia magna*	Neonates (<24 h)	19.5-21.5	250	SR, N	21 d	Body length	MATC	5.2	Dave 1984
Invertebrate	Water Flea	*Daphnia magna*	Neonates (<24 h)	19.5-21.5	250	SR, N	21 d	Reproduction	NOEC	3.7	Dave 1984
Invertebrate	Water Flea	*Daphnia magna*	Neonates (<24 h)	19.5-21.5	250	SR, N	21 d	Reproduction	LOEC	7.4	Dave 1984
Invertebrate	Water Flea	*Daphnia magna*	Neonates (<24 h)	19.5-21.5	250	SR, N	21 d	Reproduction	MATC	5.2	Dave 1984
Invertebrate	Water Flea	*Daphnia magna*	Neonates (<24 h)	20	101.6-181.3	SR, M	21 d	Survival	LC10	>142	Fieser et al. 1986
Invertebrate	Water Flea	*Daphnia magna*	Neonates (<24 h)	20	101.6-181.3	SR, M	21 d	Survival	LC20	>142	Fieser et al. 1986
Invertebrate	Water Flea	*Daphnia magna*	Neonates (<24 h)	20	101.6-181.3	SR, M	21 d	Reproduction	IC10	27.7	Fieser et al. 1986
Invertebrate	Water Flea	*Daphnia magna*	Neonates (<24 h)	20	101.6-181.3	SR, M	21 d	Reproduction	IC20	29.4	Fieser et al. 1986
Invertebrate	Wavy-Rayed Lampmussel	*Lampsilis fasciola*	juvenile	25	32	SR, M	9 d	Survival	LC50	177	Keller and Augspurger 2005
Invertebrate	Zebra Mussel	*Dreissena polymorpha*	Adult (1.5 - 2 cm)	17 ± 0.5	106 ± 14	SR, NR	17 weeks	Survival	LC50	10.0	Del Piero et al. 2012
Invertebrate	Zebra Mussel	*Dreissena polymorpha*	Adult (1.5 - 2 cm)	22 ± 0.5	106 ± 14	SR, NR	8 weeks	Survival	LC50	10.0	Del Piero et al. 2012
Algae	Algae	*Pseudokirchneriella subcapitata*	growth stage	25	14	S, NR	72 h	Growth inhibition	IC25	217	Banack et al. 2012
Algae	Algae	*Ankistrodesmus braunii*	growth stage	23	NR	S, M	7.3 d	Growth	NOEC	50	Hekman et al. 1984
Algae	Algae	*Cyclotella meneghiniana*	growth stage	23	NR	S, M	7.3 d	Growth	NOEC	50	Hekman et al. 1984
Algae	Algae	*Oscillatoria limnetica*	growth stage	23	NR	S, M	7.3 d	Growth	NOEC	50	Hekman et al. 1984
Algae	Algae	*Scenedesmus quadricauda*	growth stage	23	NR	S, M	7.3 d	Growth	NOEC	50	Hekman et al. 1984
Algae	Algae	*Stephanodiscus minutus*	growth stage	15	NR	S, M	7.3 d	Growth	NOEC	50	Hekman et al. 1984
Algae	Algae	*Synechococcus leopoliensis*	growth stage	23	NR	S, M	7.3 d	Growth	NOEC	25	Hekman et al. 1984
Algae	Algae	*Synechococcus leopoliensis*	growth stage	23	NR	S, M	7.3 d	Growth	LOEC	50	Hekman et al. 1984
Algae	Algae	*Synechococcus leopoliensis*	growth stage	23	NR	S, M	7.3 d	Growth	EC13	50	Hekman et al. 1984
Algae	Algae	*Synechococcus leopoliensis*	growth stage	23	NR	S, M	7.3 d	Growth	MATC	35	Hekman et al. 1984
Algae	Algae	*Chlorella vulgaris*	growth stage	26	double distilled water	S, N	15 d	Survival	LC50	840	Rai et al. 1998
Algae	Algae	*Chlorella vulgaris*	growth stage	26	double distilled water	S, N	15 d	Survival	LC50	588	Rai et al. 1998
Algae	Algae	*Chlorella vulgaris*	growth stage	26	double distilled water	S, N	3 d	Survival	LC50	294	Rai et al. 1998

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Algae	Algae	*Chlorella vulgaris*	growth stage	26	double distilled water	S, N	15 d	Growth	IC11	95	Rai et al. 1998
Algae	Diatom	*Nitzschia palea*	growth stage	NR	NR	S, M	4 d	Growth inhibition	NOEC	110	Joy and Balakrishnan 1990
Plant	Duckweed	*Lemna minor*	cultures in logarithmic growth stage	?	206	S, NR	7 d	Growth inhibition	IC25	229	Banack et al. 2012
Fish	Brown Trout	*Salmo trutta*	<8-week old fry; 2 cm	12	73	SR, M	10 d	Survival	LC20	5	Wright 1977
Fish	Common Carp	*Cyprinus carpio*	10–36 cm	18 - 24	7.5	S, M	20 d	Survival	LC20	25	Neuhold and Sigler 1960
Fish	Common Carp	*Cyprinus carpio*	10–36 cm	18 - 24	7.5	S, M	20 d	Survival	LC50	81	Neuhold and Sigler 1960
Fish	Rainbow Trout	*Oncorhynchus mykiss*	7 - 13 cm; 15 - 25 g	18	Soft	NR	10 d	Survival	LC50	4.8	Angelovic et al. 1961
Fish	Rainbow Trout	*Oncorhynchus mykiss*	7 - 13 cm; 15 - 25 g	18	Soft	NR	10 d	Survival	LC10	1.8	Angelovic et al. 1961
Fish	Rainbow Trout	*Oncorhynchus mykiss*	7 - 13 cm; 15 - 25 g	13	Soft	NR	10 d	Survival	LC50	3.9	Angelovic et al. 1961
Fish	Rainbow Trout	*Oncorhynchus mykiss*	7 - 13 cm; 15 - 25 g	13	Soft	NR	10 d	Survival	LC10	2.2	Angelovic et al. 1961
Fish	Rainbow Trout	*Oncorhynchus mykiss*	7 - 13 cm; 15 - 25 g	7.5	Soft	NR	10 d	Survival	LC50	6.6	Angelovic et al. 1961
Fish	Rainbow Trout	*Oncorhynchus mykiss*	7 - 13 cm; 15 - 25 g	7.5	Soft	NR	10 d	Survival	LC10	4.1	Angelovic et al. 1961
Fish	Rainbow Trout	*Oncorhynchus mykiss*	Fry	15	6	SR, NR	7 d	Growth	IC25	10.3	Banack et al. 2012
Fish	Rainbow Trout	*Oncorhynchus mykiss*	Fry	15	6	SR, NR	7 d	Growth	IC25	12.3	Banack et al. 2012
Fish	Rainbow Trout	*Oncorhynchus mykiss*	Fry	15	6	SR, NR	7 d	Growth	IC25	31.5	Banack et al. 2012
Fish	Rainbow Trout	*Oncorhynchus mykiss*	10–20 cm	12.8	7.5	S, M	20 d	Survival	LC10	1.5	Neuhold and Sigler 1960
Fish	Rainbow Trout	*Oncorhynchus mykiss*	10–20 cm	12.8	7.5	S, M	20 d	Survival	LC20	2.0	Neuhold and Sigler 1960
Fish	Rainbow Trout	*Oncorhynchus mykiss*	10–20 cm	12.8	7.5	S, M	20 d	Survival	LC50	3.6	Neuhold and Sigler 1960
Fish	White-Clawed Crayfish	*Austropotamobius pallipes*	6-mo old; 57 mm length	19.5	190	SR, M	8 d	Survival	LC50	28.9	Aguirre-Sierra et al. 2013
Fish	White-Clawed Crayfish	*Austropotamobius pallipes*	6-mo old; 57 mm length	19.5	190	SR, M	8 d	Survival	NOEC	19.4	Aguirre-Sierra et al. 2013
Fish	White-Clawed Crayfish	*Austropotamobius pallipes*	6-mo old; 57 mm length	19.5	190	SR, M	8 d	Survival	LOEC	45.1	Aguirre-Sierra et al. 2013
Fish	White-Clawed Crayfish	*Austropotamobius pallipes*	6-mo old; 57 mm length	19.5	190	SR, M	8 d	Survival	MATC	29.6	Aguirre-Sierra et al. 2013
Fish	White-Clawed Crayfish	*Austropotamobius pallipes*	6-mo old; 57 mm length	19.5	190	SR, M	8 d	Escape Response	EC50	5.9	Aguirre-Sierra et al. 2013
Invertebrate	Tubificid worm	*Branchiura sowerbyi*	NR	17 ± 0.5	NR	SR, N	18 d	Survival	LC10	>160	Casellato et al. 2013
Invertebrate	Tubificid worm	*Branchiura sowerbyi*	NR	17 ± 0.5	NR	SR, N	18 d	Survival	LC20	>160	Casellato et al. 2013
Invertebrate	Tubificid worm	*Branchiura sowerbyi*	NR	22 ± 0.5	NR	SR, N	18 d	Survival	LC10	40	Casellato et al. 2013
Invertebrate	Tubificid worm	*Branchiura sowerbyi*	NR	22 ± 0.5	NR	SR, N	18 d	Survival	LC20	60	Casellato et al. 2013
Plant	Inflated Duckweed	*Lemna gibba*	culture	26	NR	NR	3 d	Growth	EC10	4.2	Oota 1971
Plant	Inflated Duckweed	*Lemna gibba*	culture	26	NR	NR	3 d	Reduction in flowers	EC18	0.42	Oota 1971
Plant	Inflated Duckweed	*Lemna gibba*	culture	26	NR	NR	3 d	Reduction in flowers	EC50	4.2	Oota 1971

LCx = concentration of sample estimated to be lethal to x% of the test organisms.

ECx = concentration of sample estimated to cause a specified effect to x% of the test organisms.

ICx = the inhibiting concentration for an x% effect; it is the concentration of sample estimated to cause x% reduction in growth or fecundity of the test organisms.

MATC = maximum acceptable toxicant concentration; the geometric mean of the NOEC and LOEC.

NR = No data reported; S = Static; SR = Static-Renewal; FT = Flow-through; N = Nominal; M = Measured; NOEC = no observed effect concentration; LOEC = lowest observed effect concentration;
h = hours; d = days; mo = months; g = gram; mm = millimetre; cm = centimetre; mg/L F= milligrams per litre fluoride; mg/L CaCO3 = milligrams per litre calcium carbonate ;% = percent; >= greater than; <= less than; ± = plus or minus; °C = degrees Celsius.