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Scientific Criteria Document for the Development of the Canadian Water Quality Guidelines for

BORON

PN 1437

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PREFACE

CCME has recently updated the 1991 protocol for the derivation of Water Quality Guidelines for the Protection of Aquatic Life (WQGPAqL) and developed a tiered approach to guideline derivation, which now includes the use of a statistical extrapolation method in addition to the original assessment factor approach. This updated protocol has been peer reviewed and adopted as the new tiered approach. The first tier of the CCME (2007) national approach is to make use of species sensitivity distributions (SSDs). This approach uses all available toxicity data for species to derive the final guideline as the data is fitted to a specified model or distribution, from which is calculated an exposure concentration that is to be protective of a specified percentage of species (e.g. 95%). If the data is insufficient to model an SSD curve, then a second or third tier guideline would be developed using an assessment factor method approach (dividing the lowest toxicity value from a high quality study by an uncertainty or safety factor), which is similar to the 1991 CCME guideline development protocol.

The 2007 CCME protocol for the derivation of WQGPAqL now provides guidance on setting both a short-term benchmark concentration and a long-term guideline. Short-term exposure benchmark concentrations are meant to protect only a specified fraction of individuals for a defined short-term exposure period from severe effects such as lethality or immobilization, as a result of spill events to aquatic-receiving environments or from infrequent releases of short-lived/non-persistent substances (CCME, 2007). In contrast, long-term exposure guidelines adhere to the CCME guiding principle and are meant to protect all forms of aquatic life (all species, all life stages) for indefinite exposure periods (CCME, 2007). There are three tiers in place for the setting of CCME (2007) WQGPAqL. **Type A** guidelines are derived using a species sensitivity distribution (SSD) approach when there are adequate primary and secondary toxicity data to satisfactorily fit a SSD curve. **Type B** guidelines are derived for substances that either have inadequate or insufficient toxicity data for the SSD approach (i.e., Type A guideline), but for which enough toxicity data from a minimum number of primary and/or secondary studies are available. The Type B guideline approach is further divided into the **Type B1** and **Type B2** guidelines, based upon the quantity and quality of available toxicity data.

In this report, a Type A short-term boron benchmark concentration and a long-term boron water quality guideline for the protection of aquatic life have been developed using the national species sensitivity distribution method (CCME, 2007).

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SUMMARY

CCME Water Quality Guidelines for the Protection of Aquatic Life (CWQGs PAL) abide by the following general guiding principle: to protect all forms of aquatic life and all aspects of aquatic life cycles. The clear intention is to protect all species during all life stages during indefinite exposure to the water. CCME has recently updated the 1991 protocol for the derivation of CWQGs PAL and developed a tiered approach to guideline derivation, which now includes the use of species sensitivity distributions in addition to the original assessment factor approach. In this report, boron water quality guidelines for the protection of aquatic life have been developed using the national species sensitivity distribution method (or SSD Type A guideline derivation method). Both a short-term exposure benchmark concentrations (29 mg/L) and a long-term (1.5 mg/L) exposure guideline have been developed. Short-term exposure benchmark concentrations are derived using severe effects data (such as lethality) of defined short-term exposure periods (24-96 h). These benchmark concentrations identify estimators of severe effects to the aquatic ecosystem and are intended to give guidance on the impacts of severe, but transient, situations (e.g., spill events to aquatic receiving environments and infrequent releases of short-lived/nonpersistent substances). Short-term benchmark concentrations *do not* provide guidance on protective levels of a substance in the aquatic environment, as short-term benchmark concentrations are levels which *do not* protect against adverse effects. Long-term exposure guidelines are intended to protect all forms of aquatic life for indefinite exposure periods (≥ 7d exposures for fish and invertebrates, ≥24h exposures for aquatic plants and algae).

Canadian Water Quality Guideline (CWQG) for Boron (mg L^{-1}) for the Protection of Aquatic Life

	Long-Term Exposure Guideline	**Short-Term Exposure Benchmark Concentration**
Freshwater	1.5	29
Marine	NRG	NRG

NRG = No recommended guideline

RÉSUMÉ

Les Recommandations canadiennes pour la qualité des eaux en vue de protéger la vie aquatique (RCQE-PVA) reposent sur le même principe directeur général, soit protéger toutes les formes de vie aquatique et tous les aspects des cycles biologiques en milieu aquatique. Elles visent à protéger toutes les espèces à tous les stades de vie pendant des périodes d'exposition indéterminées dans le milieu aquatique. Le CCME a récemment mis à jour le protocole d'élaboration des RCQE-PVA de 1991 et a développé une démarche en plusieurs étapes qui tient compte de la distribution de la sensibilité des espèces (DSE) en plus des facteurs d'évaluation déjà utilisés. Dans le présent rapport, les recommandations relatives au bore ont été élaborées à l'aide de la méthode nationale de la DSE (méthode d'élaboration de recommandations de type A). Une recommandation pour une exposition de courte durée (29 mg/L) et une recommandation pour une exposition de longue durée (1,5 mg/L) ont été élaborées. Les recommandations pour une exposition de courte durée sont élaborées au moyen de données sur les effets graves (comme la létalité) associés à des périodes d'exposition de courte durée bien définies (de 24 à 96 h). Elles donnent une indication des concentrations pouvant entraîner des effets graves pour les écosystèmes aquatiques et renseignent sur les impacts d'événements graves, mais transitoires (p. ex. déversements dans le milieu aquatique et rejets peu fréquents de substances non persistantes ou à courte durée de vie). Elles *ne donnent pas* d'indication sur les concentrations qui assurent la protection des organismes aquatiques et *ne protègent pas* contre les effets nocifs des substances. Les recommandations pour une exposition de longue durée visent à protéger toutes les formes de vie aquatique pendant des périodes d'exposition indéterminées (≥ 7 jours pour les poissons et les invertébrés et ≥ 24 h pour les végétaux aquatiques et les algues).

Recommandations canadiennes pour la qualité des eaux (RCQE) en vue de protéger la vie aquatique – bore (mg L^{-1})

	Exposition de longue durée	Exposition de courte durée
Eaux douces	1.5	29
Eaux marines	AR	AR

AR = aucune recommandation

1.0 INTRODUCTION

1.1 Production and Uses

Boron is ubiquitous in the environment, occurring naturally in over 80 minerals and constituting 0.001% of the Earth's crust (U.S. EPA, 1987). The highest concentrations of boron are found in sediments and sedimentary rock, particularly in clay rich marine sediments. The high boron concentration in seawater (4.5 mg B/L), ensures that marine clays are rich in boron relative to other rock types (Butterwick *et al*., 1989). The most significant source of boron is seasalt aerosols, where annual input of boron to the atmoshphere is estimated to be 1.44 Tg B/year, where Tg = 10^{12} g (Park and Schlesinger, 2002). In addition to atmospheric deposition, boron is also released into the environment very slowly at low concentrations by natural weathering processes. Due to the extensive occurrence of clay-rich sedimentary rocks on the Earth's land surfaces, the majority of boron mobilized into soils and the aquatic environment by weathering probably stems from this source. Natural weathering is estimated to release more boron into the environment worldwide than industrial sources (Butterwick *et al*., 1989) as boron is tied up in many industrial products such as glass. Natural weathering (chemical and mechanical) of minerals from carbonate rocks has been estimated to mobilize 0.193 Tg B/year (Park and Schlesinger, 2002). Other natural sources include volcanic emissions (0.017-0.022 Tg B/yr), soil dust (0.017-0.033 Tg B/yr), and plant aerosols (0.004 Tg B/yr). Volcanic emissions release boric acid and boron trifluoride; therefore, the concentrations of boron in water in volcanic regions are high (Health Canada, 1990). The evaporation of sea water from closed basins is a commercial source of boron (Durocher, 1969). The estimated amounts of boron introduced into the atmosphere as a result of fossil fuel combustion, biomass burning and other human activities (e.g. manucturing and incineration) are 0.20, 0.26-0.43, and 0.07 Tg B/yr, respectively (Park and Schlesinger, 2002).

Boron is produced anthropogenically by the chemical reduction of boron compounds with reactive metals, either by non-aqueous electrolytic reduction or thermal decomposition. Highly purified boron is produced by zone-refining or other thermal techniques (Stokinger, 1981; U.S. Bureau of Mines, 1989). Borax, found in playa (intermittent) lakes and other evaporite deposits, is used to produce refined sodium borate compounds and boric acid (ATSDR, 1992).

Borates and boric acids are used in glass manufacturing (fiberglass, borosilicate glass, enamel, frit, and glaze), soaps and detergents, flame retardants, and neutron absorbers for nuclear installations (WHO, 2003). Boric acid, borates and perborates have been used in mild antiseptics, cosmetics, pharmaceuticals, as antioxidants for soldering, cleaning products/ detergents, boron neutron capture therapy and agricultural fertilizers (WHO, 2003). Boron compounds are also used in the leather, textile, paint and wood-processing industries (Health Canada, 1990). Borax (or sodium tetraborate) and boric acid are used as insecticides in Canada (Health Canada, 1990). Borax is also used extensively as a cleaning agent and an antimicrobial agent (Health Canada, 1990).

1.2 Aquatic Sources, Properties and Fate

The wet deposition of boron over the continents is estimated to be approximately 0.50 Tg B/yr, where rainwater from continental sites contains less boron when compared to boron from coastal and marine sites (Park and Schlesinger, 2002). Natural weathering (chemical and mechanical) of boron-containing rocks is a major source of boron compounds in water (Butterwick *et al*., 1989) and on land (Park and Schlesinger, 2002). The amount of boron released into the aquatic environment varies greatly depending on the surrounding geology. Boron compounds also are released to water in municipal sewage and in waste waters from coal-burning power plants, irrigation, copper smelters and industries using boron (ATSDR, 1992; Howe, 1998). The boron content of wastewater discharges can be significant as borate compounds are present in domestic washing agents (WHO, 2003). With respect to Canadian wastewater discharges, a literature review was conducted to characterize the state of knowledge of municipal effluent (Hydromantis Inc., 2005). The study reported that boron releases from two Western Canadian wastewater treatment plants, releasing either raw or primary treated effluent, ranged from 110 to 180 µg/L (or 0.11 to 0.18 mg/L). Therefore, the study indicates that municipal wastewater effluent in Canada is less likely to be a source, and boron concentrations in water are more likely dependant on the leaching of boron from the surrounding geology (WHO, 2003).

The physical and chemical properties of boron and its aqueous forms are shown in Tables 1-1, 1-2, and 1-3. Elemental boron is insoluble and inert in aqueous solutions. Boron compounds rapidly transform to borates, the naturally occurring forms of boron, when exposed to water. However, no further degradation is possible. The only significant mechanism expected to influence the fate of boron in water is adsorption-desorption reactions with soil and sediment (Rai *et al.*, 1986). The extent of boron adsorption depends on the pH of the water and concentration of boron in solution. The greatest adsorption is observed between a pH of 7.5 and 9.0 (WHO, 2003).

In natural waters, boron forms stable species and exists primarily as undissociated boric acid [$B(OH)_3$] and complex polyanions (*e.g.*, $B(OH)_4^-$) (Health Canada, 1990; Howe, 1998; WHO, 2003). These forms of boron are highly soluble and not easily removed from solution by natural mechanisms. Borate and boric acid are in equilibrium depending on the pH of the water. At an acidic pH, boron exists in solution mainly as undissociated boric acid, whereas at alkaline pH it is present as borate ions (Howe, 1998).

Table 1- 1 Physical - Chemical Properties Boron

Compound: Boron	Chemical Formula: B	CAS No: 7440-42-8

Properties		
Molecular Weight (MW):	10.81 g/mol	Budavari *et al*., 1989; Weast, 1985; Lide, 2000; Clayton and Clayton, 1982; Sax, 1984; Windholz, 1983; Moss and Nagpal, 2003
Melting Point:	2,075 °C (Lide, 2000) - 2,300 °C (Weast, 1985; U.S. EPA, 1975)	
Boiling Point:	2,550 (Weast, 1985) - 4,000 (Lide, 2000)	
Physical State at Standard Temperature and Pressure:	Solid	Weast, 1985; WHO, 2003; Moss and Nagpal, 2003
Dissociation Constant:	no data	
Liquid Density (D):	2.34 g/cm^3 at 20 °C	Weast, 1985; U.S. EPA, 1975
Molar Volume (MW/D):	4.62 cm^3/mol (calc.)	
Vapour Pressure (Pa):	1.56x10^{-5} atm at 2,140 °C	Windholz, 1983; O'Neil, 2001; Budavari *et al*., 1989
Water Solubility:	Insoluble	Weast, 1985; Windholz, 1983; Clayton and Clayton, 1982; Hawley, 1981; Budavari *et al*., 1989; U.S. EPA, 1975
Henry's Law Constant (Ps/Cs):	no data	

Persistence	
B.O.D. (mg/L)	no data
Breakdown Products:	Boron does not degrade in the environment (ATSDR, 1992)
Half Life (Days):	no data

Octanol-Water Partition Co-efficient (Kow)	
Range of Available Kow Values:	Adsorption constants for inorganic constituents cannot be predicted *a priori* (ATSDR, 1992)
Final Chosen Log Kow Value:	no data

Table 1- 2 Physical - Chemical Properties Boron

Compound: Boric acid	Chemical Formula: BH_3O_3	CAS No:010043-35-3

Properties		
Molecular Weight (MW):	61.833 (Lide, 2000) - 69.92 g/mol (Weast, 1985)	
Melting Point:	169°C (Weast, 1985; U.S. EPA, 1975) - 171°C (Budavari *et al*., 1989; Lide, 2000)	
Boiling Point:	300°C	Weast, 1985; U.S. EPA, 1975
Physical State at Standard Temperature and Pressure:	Solid	Weast, 1985; CHEMINFO, 1996
Dissociation Constant:	5.8×10^{-10} at 25°C (pKa=9.24)	Kirk-Othmer, 1992
Liquid Density (D):	1.435 g/cm3 at 15°C	Lewis, 1999
	2.46 g/cm^3 at 20°C	Weast, 1985
Molar Volume (MW/D):	no data	
Vapour Pressure (Pa):	negligible at 20°C	Bingham *et al*., 2001
Water Solubility:	47.2 g/L at 25°C	Kirk-Othmer, 1992
	50 g/L at 25°C	Shiu *et al*., 1990
	63.5 g/L at 30°C	Weast, 1985; U.S. EPA, 1975
	276 g/L at 100°C	U.S. EPA, 1975
Henry's Law Constant (Ps/Cs):	no data	

Persistence	
B.O.D. (mg/L)	no data
Breakdown Products:	No biotransformation processes have been reported for boron compounds (O'Neil, 2001)
Half Life (Days):	no data

Octanol-Water Partition Co-efficient (Kow)	
Range of Available Kow Values:	no data
Final Chosen Log Kow Value:	no data

Table 1- 3 Physical - Chemical Properties

Compound: Borax	Chemical Formula: $Na_2B_4O_7$	CAS No: 1303-96-4

Properties		
Molecular Weight (MW):	381.37 g/mol	Weast, 1985; NIOSH, 2003; Lide, 2000
Melting Point:	60-75°C	Weast, 1985; U.S. EPA, 1975 (75°C); Lide, 2000 (75°C)
Boiling Point:	320°C	Weast, 1985; U.S. EPA, 1975; NIOSH, 2003
Physical State at Standard Temperature and Pressure:	Solid	NIOSH, 2003
Dissociation Constant:	no data	
Liquid Density (D):	1.73 g/cm^3 at 20°C	Weast, 1985; NIOSH, 2003; Lide, 2000
Molar Volume (MW/D):	no data	
Vapour Pressure (Pa):	0 mmHg (approx)	NIOSH, 2003; Lide, 2000
Water Solubility:	20 g/L at 0°C	Weast, 1985; U.S. EPA, 1975
	59.3 g/L at 25°C	Shiu *et al* ., 1990
	1,700 g/L at 100°C	U.S. EPA, 1975
Henry's Law Constant (Ps/Cs):	no data	

Persistence	
B.O.D. (mg/L)	no data
Breakdown Products:	No biotransformation processes have been reported for boron compounds (O'Neil, 2001)
Half Life (Days):	no data

1.3 Ambient Concentrations in Canadian Waters

The majority of the Earth's boron is found in the oceans, with an average concentration of 4.5 mg/L (Weast, 1985). The amount of boron in fresh water depends on factors such as the proximity to marine coastal regions, inputs from industrial and municipal effluents and the geochemical nature of the drainage area (Butterwick *et al*., 1989). Naturally-occurring boron is present in groundwater, primarily as a result of leaching from rocks and soils containing borates and borosilicates (WHO, 2003).

Concentrations of boron in the surface water of Canada and the USA ranged from 0.02 to 360 mg/L (WHO, 1998). High boron concentrations are indicative of boron-rich deposits. Typical boron concentrations were less than 0.1 mg/L, with a 90th percentile concentration of 0.4 mg/L (WHO, 1998). Sekerka and Lechner (1990) measured boron concentrations in surface water samples obtained from various locations in Ontario. Boron concentrations ranged from 0.025 to 0.072 mg/L (Table 1-4). In addition, historical dissolved, particulate and total boron concentrations in Lake Superior (1983) and Lake Ontario (1985) were characterized by Rossmann and Barres (1988) (Table 1-5).

Table 1- 4 Boron Ontario Surface Water Concentrations (mg/L)[a]

Sample Location	Mean Boron Concentration (SD) (mg/L)
Burlington Bay	0.0654
Hidden Valley Creek	0.0524
Roseland Creek	0.0303
Shore Acres Creek	0.0379
Appleby Creek	0.0342
Lake Ontario	0.0323 ($1.17\text{x}10^{-3}$)
Lake Ontario (Bay I)	0.0719 ($3.5\text{x}10^{-4}$)
Lake Ontario (Bay II)	0.0630 ($1.92\text{x}10^{-3}$)
Lake Ontario	0.0251
Hamilton Bay	0.0593
Northern Ontario bog water	0.0533

[a] Obtained from Sekerka and Lechner, 1990

Table 1- 5 Historical (1983 to 1985) Boron Surface Water Concentrations (mg/L) in Lake Superior and Lake Ontario

Boron Form	**Boron Concentration (mg/L)**	
	Lake Superior	**Lake Ontario**
Dissolved	0.027	0.047
Particulate	0.0009	0.0055
Total	NA	0.058

NA Not available

The National Water Quality Monitoring Office of Environment Canada provided boron concentration data measured in surface waters from various locations across Canada (C. Lochner 2008, pers. com.). This data is presented in Table 1-6. Boron concentrations ranged from 0.0001-0.951 mg L^{-1} (extractable) in Nova Scotia, 0.008-0.13 mg L^{-1} (extractable) and 0-0.607 mg L^{-1} (total) in Newfoundland, and 0.0001-0.402 mg L^{-1} (extractable) in New Brunswick. For Ontario, data was provided for the Great Lakes and Great Lake connecting channels. Total boron concentrations ranged from 0.006-0.011 mg L^{-1} in Lake Superior, 0.004-0.018 mg L^{-1} in Lake Huron, 0.007-0.011 mg L^{-1} in Georgian Bay, 0.015-0.031 mg L^{-1} in Lake Erie and 0.018-0.077 mg L^{-1} in Lake Ontario. Total boron concentrations measured in the St. Clair River, Niagara River and St. Lawrence River were 0.009-0.021 mg L^{-1}, 0.018-0.032 mg L^{-1}, and 0.02-0.032 mg L^{-1}, respectively. Surface water total boron concentrations ranged from 0.0052-0.271 mg L^{-1} in Manitoba, 0.0001-2.58 mg L^{-1} in Saskatchewan, 0.0001-0.082 mg L^{-1} in Alberta, 0.0001-2.3 mg L^{-1} in the Northwest Territories, and 0.0001-0.006 mg L^{-1} in the Yukon.

Table 1- 6 Boron Surface Water Concentrations in Canada (mg/L)

Sample Location	Total Boron Concentration Range	Extractable Boron Concentration Range	Dissolved Boron Concentration Range
Maritimes			
New Brunswick	NA	0.0001 - 0.402	NA
Newfoundland	0 - 0.607	0.008 - 0.13	NA
Nova Scotia	NA	0.0001 - 0.951	NA
Ontario - Great Lakes			
Lake Superior	0.006 - 0.011	NA	NA
Lake Huron	0.004 - 0.018	NA	NA
Georgian Bay	0.007 - 0.011	NA	NA
Lake Erie	0.015 - 0.031	NA	NA
Lake Ontario	0.018 - 0.077	NA	NA
Ontario - Great Lakes Connecting Channels			
St. Clair River	0.009 - 0.021	NA	NA
Niagara River	0.018 - 0.032	0.016 – 0.0245	NA
St. Lawrence River	0.02 - 0.032	0.0229 – 0.0252	NA
Praries			
Manitoba	0.0052 - 0.271	0.01 – 0.11	0.002 – 0.219
Saskatchewan	0.0001 - 2.58	NA	0.0001 – 2.71
Alberta	0.0001 - 0.082	0.01 – 0.13	0.0001 – 0.242
Territories			
Northwest Territories	0.0001 - 2.3	0.01 – 0.16	0.0001 – 0.0568
Yukon Territory	0.0001 - 0.006	0.01	0.0016 – 0.0059

In Quebec, recent data (2004-2006) were obtained in clean conditions, on the acid soluble fraction. Of the 23 rivers sampled, the median boron concentrations ranged from 0.0021 to 0.058 mg/L with a median concentration for all the rivers of 0.0063 mg/L (MDDEP, 2007 unpublished data).

2.0 TOXICITY TO AQUATIC ORGANISMS

Criteria used for classifying available toxicity data as either primary or secondary information are described in "*A Protocol for the Derivation of Water Quality Guidelines for the Protection of Aquatic Life*" (CCME, 2007). The studies from which data was collected to develop the CWQGPAqL were screened against the CCME (2007) data classification criteria. A summary of the collected data, as well as the qualifier for each study, are compiled in Appendix A. Many of the studies listed in Appendix A were utilized by the British Columbia Ministry of Water, Land and Air Protection (BC MOE) for the derivation of a water quality guideline for boron (1.2 mg/L) for the protection of aquatic life (Moss and Nagpal, 2003). Study classifications (primary, secondary, unacceptable) utilized by British Columbia (Moss and Nagpal, 2003) are those utilized by CCME (2007). For this reason, study classifications found in Moss and Nagpal (2003) were adopted if available or the original paper was reviewed to determine data quality. In general, primary toxicity studies involved acceptable test procedures, conditions and controls, measured toxicant concentrations and flow-through or renewal exposure conditions. Secondary toxicity studies usually involved unmeasured toxicant concentrations, static bioassay conditions, controls, pseudoreplication and may employ a wider array of methods. Unclassified toxicity information was also obtained from the BC MOE Ambient Water Quality Guidelines document for boron (Moss and Nagpal, 2003). For CWQGPAqL development, the original scientific publications were obtained for review and classification purposes, where possible. In the case where it was not possible to retrieve the original publications, this unclassified toxicity information obtained from Moss and Nagpal (2003) was classified as secondary quality by default.

Acute toxicity studies generally involved test durations of 96 hours or less for vertebrates or 48 hours or less for invertebrates (the CCME 2007 protocol indicates that 24-96h exposures are short term exposures). Chronic toxicity data studies include complete life cycle tests and partial life cycle tests involving early life stages (the CCME 2007 protocol indicates that long-term exposure is defined as being ≥7d for fish and invertebrates and ≥24h for aquatic plants and algae).

2.1 Acute Toxicity

2.1.1 Vertebrates

Primary acute toxicity data for animals exposed to boron were available for early life stages of largemouth bass (*Micropterus salmoides*), fathead minnow (*Pimephales promelas*), rainbow trout (*Oncorhynchus mykiss*) and coho salmon (*Oncorhynchus kisutch*). Endpoints ranged from a 3 day NOEC (teratogenesis at hatching) of 0.109 mg/L for embryo-hatching stages of largemouth bass (Black *et al.*, 1993) to a 7 day EC_{50} (embryo test) of 969 mg/L for rainbow trout (MELP, 1996). The reported effect concentrations for fathead minnow were a 48 and 96 hour LC50 of 348 and 64.3 mg/L, respectively (MOE, 2007). The lowest reported 96 hour LC_{50} values for coho salmon and rainbow trout were 304.1 mg/L (MELP, 1996) and 275 mg/L (MOE, 2007), respectively.

Secondary acute toxicity data were available for embryo and juvenile life stages of frog (*Xenopus laevis*), bluegill sunfish (*Lepomis macrochirus*), zebrafish (*Danio rerio*), bonytail (*Gila elegans*), Colorado squawfish (*Ptychocheilus lucius*), razorback sucker (*Xyrauchen texanus*), mosquito fish (*Gambusia afinis*), coho salmon (*Oncorhynchus kisutch*), and chinook salmon (*Oncorhynchus tshawytscha*). The lowest effect concentration was a 24 hour TLm of 4.6 mg/L for the bluegill sunfish (Turnbull et al., 1954), whereas the highest effect concentration was 24-hour TLm of 3,145 mg/L for the mosquito fish (Wallen et al., 1957). The following lists the lowest reported endpoints for the frog (4-d NOEC or 35.9 mg/L) (Fort et al., 1999), and mosquito fish (96-h NOEC of <204 mg/L) (Wallen et al., 1957). The lowest reported 96-hour LC_{50} values for bonytail, Colorado squawfish and razorback sucker were 280, 279 and 233 mg/L, respectively (Hamilton, 1995). Hamilton and Buhl (1990) reported the lowest 96 hours LC_{50} values for coho and Chinook salmon of 447 and 566 mg/L, respectively. Rowe *et al.* (1998) investigated 96 hour embryonic mortality of zygote zebrafish. A LOEC of 99.5 mg/L was reported based on 88% mortality (Rowe *et al.*, 1998).

Unclassified acute toxicity data were available for the rainbow trout, minnow and toad (*Bufo vulgaris*). The lowest LC_{50} value for the rainbow trout was 339 mg/L (48 hours) (Sprague, 1972 in Birge and Black, 1977;). A minnow (species not identified) experienced a median lethal dose (TLm or LC_{50}) at boron concentrations ranging from 340 to 374 mg/L with an unknown exposure duration (McKee and Wolf, 1963). The lowest effect concentration for toad embryos was 874 mg/L for malformations occurring after 24 hours of boric acid exposure (U.S. EPA, 1975).

2.1.2 Invertebrates

Primary acute toxicity data for invertebrates exposed to boron were available for the amphipod (*Hyalella azteca*), water flea (*Daphnia magna*), and midges (*Chironomus decorus, C. tentans*). 48 hour LC_{50} concentrations ranged from 21.3 mg/L for neonate water fleas (MELP, 1996) to 1,376 mg/L for larvae midge *C. decorus* (Maier and Knight, 1991). The lowest 96 hour LC_{50} for the amphipod was 28.9 mg/L (MELP, 1996).

Secondary acute toxicity data was available for the water flea, where neonates exposed to boron displayed a 48-h LC50 of 133 mg/L (Gersich, 1984).

Kapu and Schaeffer (1991) examined the effects of boron exposure to the planarian (*Dugesis dorotocephala*) under static conditions with unmeasured concentrations. Effect concentrations ranged from 1 to 10 mg/L for hyperkinesias, spiraling and head/nose twist within five minutes of boron exposure. Toxicity data reported by Kapu and Schaeffer (1991) were classified as unacceptable as toxicity endpoints were evaluated using an arbitrary ranking scale for behavioural abnormalities and the responses observed at 1 to 5 minutes were not observed at 10 to 30 minutes or 40 to 60 minutes during the 1 hour behavioural test.

Unclassified acute toxicity data were available for the protozoan (*Entosiphon sulcatum*), mosquito larvae (*Anopheles quadrimaculatus*) and three unspecified species of mosquito larvae. Effect concentrations ranged from a threshold concentration of 1 mg/L for a reduction in cell replication for the protozoan (Bringmann, 1978) to a 48 hour LC_{100} of 2,797 mg/L for pupae of three mosquito larvae (U.S. EPA, 1975). The lowest effect concentration for mosquito larvae was 92% mortality after a 48 hour exposure to a boron concentration of 25 mg/L (Fay, 1959). Gersich (1984) exposed water fleas to boric acid and reported a 48 hour LC_{50} of 133 mg/L.

2.2 Chronic Toxicity

2.2.1 Vertebrates

Primary chronic toxicity data for vertebrates were available for rainbow trout, largemouth bass and fathead minnow. Black *et al*. (1993) exposed embryo and larval stage rainbow trout and largemouth bass to boric acid under flow through conditions with measured concentrations. Effect concentrations for embryo-larval rainbow trout ranged from a 32 day LOEC (mortality) of 0.1 mg/L to a 32 day LC_{50} of 138 mg/L (Black *et al.*, 1993). The lowest effect concentration for embryo-larval stage largemouth bass was an 11 day LOEC (mortality) of 12.17 mg/L, while the highest was an 11 day LC_{50} of 92 mg/L (Black *et al.*, 1993). Larval fathead minnow (*Pimephales promelas*) were exposed to boron for a 7-d period using a static renewal exposure, with a resulting IC_{25} (growth inhibition) of 20.6 (8.5-26.5 mg/L 95% CI)(MOE 2007, unpublished data).

Secondary chronic toxicity data for vertebrates were available for embryo larval stages of rainbow trout, goldfish (*Carassius auratus*), channel catfish (*Ictalurus punctatus*), leopard frog (*Rana pipiens*), Fowler's toad (*Bufo fowleria*), as well as for blastula life-stage eggs of the wood frog (*Rana sylvatica*), Jefferson salamander (*Ambystoma jeffersonianum*), spotted salamander (*Ambystoma maculatum*), American toad (*Bufo americanus*) and alevin/fry coho salmon. The majority of the secondary toxicity data was reported by Birge and Black (1977) who exposed early life stages of various fish and amphibian species under continuous flow-through conditions to boric acid and borax at two different levels of water hardness (50 or 200 mg $CaCO_3$/L). The lowest effect concentration reported by Birge and Black (1977) was a 28 day LOEC of 0.01 mg/L for embryo-larval stages of rainbow trout. The lowest LOEC values for channel catfish (9 day), goldfish (7 day), leopard frog (7 day), and Fowler's toad (7 day) were 1, 8.33, 9.6, and 53.5 mg/L, respectively (Birge and Black, 1977). A study conducted by Davis and Mason (1973) which exposed alevins and fry coho salmon to sodium metaborate reported a 23 day LC_{50} of 93 mg/L. Laposta and Duncan (1998) exposed various amphibian eggs to sodium tetraborate under static conditions with measured concentrations. The lowest effect concentration for wood frog, Jefferson salamander and spotted salamander blastula life-stage eggs was 50 mg/L for deformed hatchlings (Laposta and Duncan, 1998). Blastula life-stage American toad eggs also had a LOEC of 50 mg/L for the proportion of eggs hatching. Rowe *et al*. (1998) reported a 6 week LOEC of 108 mg/L for embryonic mortality of embryo rainbow trout exposed to boric acid.

Unclassified chronic toxicity data were available for early life stages of rainbow trout, largemouth bass, zebrafish (*Brachydanio rerio*), and the fathead minnow. The lowest effect concentration for the rainbow trout, largemouth bass, zebrafish and fathead minnow was a 32 day LOEC of 0.1 mg/L (Birge and Black, 1981), an 11 day LOEC of 12.17 mg/L (Birge and Black, 1981), a 32 day MATC of 10.04 mg/L (Hooftman et al., 2000), and a 32 day LOEC for growth of 24 mg/L (Procter and Gamble, unpublished), respectively.

Of all of the species and life stages investigated in boron aquatic toxicity studies, the early life stages of rainbow trout appear to be the most sensitive in chronic exposures, based on the data presented in Appendix A. Considerable variability is observed between the no-effect and lowest effect concentrations of boron in studies conducted with embryo-larval stages of the trout (Birge and Black, 1977; Black et al., 1993). Consistent concentration-related lowest observed effect levels in these studies for early life stages of the rainbow trout range from <0.1 to >17.0 mg/L Figure 2). The flat dose-response curve observed for boron over the lower end of the exposure range may have complicated the determination of precise no-effect and lowest effect values (Black *et al*., 1993). For instance, in studies conducted by Birge and Black (1977), it was common to see control-adjusted effects that ranged from two to eight percent for exposure concentrations spanning two to three orders of magnitude (Figure 1).

The flat dose-response curve may be partially attributed to the endpoints utilized. For instance, the frequency of teratogenesis included in studies conducted by Birge and Black (1977) have not been found to increase as proportionately with exposure concentrations as does mortality. Therefore, for trout stages exposed to boron it appears that the threshold effect for toxicity may be observed over a rather extensive concentration range (Black *et al.*, 1993). Given the variability of the test response data, only consistent dose-response effects (such as mortality) should be considered in the development of aquatic guidelines for boron (Black *et al*., 1993).

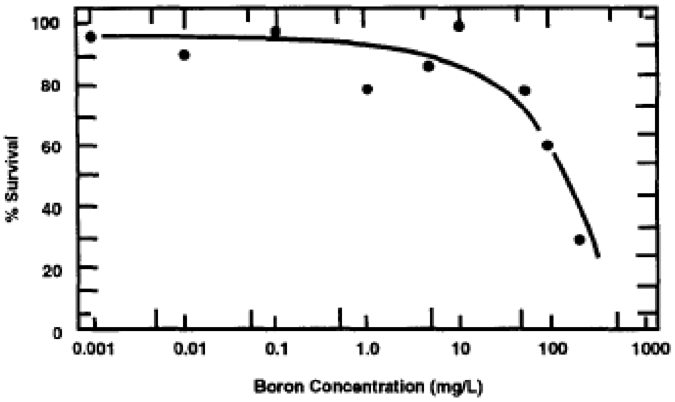


Figure 1 The Effects of Boric Acid Administered to Embryo-Larval Stages of Trout in Soft Water (Birge and Black, 1977)

Compared with other research, the Birge and Black studies have consistently found very low concentration toxicity levels for a variety of aquatic species. However, other scientists and studies have not been able to reproduce these values using similar conditions and species (Moss and Nagpal, 2003). The toxicity data points of concern include the 28 day LOEC of 1.0 mg/L from Birge and Black (1977) and the 32 day LOEC of 0.1 mg B/L (Birge and Black, 1981) for early life-stage rainbow trout. Similar low effect concentrations for rainbow trout were observed in Black *et al*. (1993) when using reconstituted water (hardness = 188±10 mg/L as $CaCO_3$, alkalinity = 54±7 mg/L as $CaCO_3$, pH = 7.7±0.2), but not when using well water (hardness = 24-39 mg/L as $CaCO_3$, alkalinity = 25-38 mg/L as $CaCO_3$, pH = 6.8-7.1). In the case of exposures with well water, no significant adverse effects were observed following an 87-day exposure with embryo trout and larvae to measured boron concentrations ranging from 2.1 to 18 mg/L (Black et al. 1993). A further study by Birge *et al.* (1983) found that 5% of rainbow trout had boron induced teratogenesis at levels of 0.001 mg/L. Moss and Nagpal (2003) found that these specific data points for rainbow trout fell below the BC MOE guideline for boron for the protection of aquatic life, and were significantly lower than the other toxicity values for vertebrates. Therefore, Moss and Nagpal (2003) considered these data points to be outliers and they were not considered in the development of the British Columbia guideline. These outliers also were not considered for CWQGPAqL development.

2.2.2 Invertebrates

Primary chronic toxicity data were available for the water flea (*D. magna*) and midge (*C. decorus*). Effect concentrations ranged between a 21 day LOEC (mean brood size) of 13 mg/L to a 21 day LC_{50} of 53.2 mg/L for the water flea (Lewis and Valentine, 1981). The lowest effect concentration for larval midge was a 96 hour LOEC (growth rate) of 20 mg/L (Maier and Knight, 1991).

Secondary chronic toxicity data was also availablefor the water flea *Daphnia magna* and *Ceriodaphnia dubia*, the amphipod (*Hyalella azteca*), and for a protozoa (*Opercularia bimarginata*). The lowest effect concentrations for *D. magna* and *C. dubia* was a 21 day MATC for growth of 4.67 mg/L (ANZECC, 2000) and a 14 day MATC for growth/reproduction of 13.4 mg/L (Hickey, 1989). Two 7 day LC_{50}s were reported for the amphipod, being 2.935 and >3.15

mg/L, respectively, for soft water and tap water (Borgmann *et al*., 2005). A 72 hour NOEC of 10 mg/L was reported for the protozoa (Guhl, 1992b).

Unclassified chronic toxicity data for aquatic vertebrates were available for the water flea (*D. magna*) and for two protozoan species (*Entosiphon sulcatum* and *Paramecium caudatum*). The lowest effect concentration for the water flea was a threshold concentration for immobilization of <0.38 mg/L (McKee and Wolf, 1963).

2.2.3 Other Organisms (Algae, Macrophytes, etc.)

Primary chronic toxicity data were available for 4 to 7 day old green algae (*Selenastrum capricornutum*) (MELP, 1997). Algae were exposed to boron for 72 hour under static conditions. The lowest reported effect concentration was a 72 hour LOEC of 12.3 mg/L. Secondary toxicity data were available for the blue green algae (*Anacystis nidulans*), the green algae (*Chlorella pyrenoidosa*), the duckweed (*Spirodella polyrrhiza*), American waterweed (*Elodea canadensis*), stream water-crowfoot (*Ranunculus penicillatus*), water milfoil (*Myriophyllum alterniflourum*), common reed (*Phragmites australis*), the duckweed (*Lemna minor*), chlorella algae (Chlorella vulgaris), the green algae (*Scenedesmus subpicatus*), and the spiked or Eurasian watermillfoil (*Myriophyllum spicatum*). The effect concentrations range from a 10 day LOEC of 3.5 mg/L for frond production for the duckweed (*Spirodella polyrrhiza*) (Davis et al., 2002) to a 32 day EC50 of 171 mg/L for the spiked or Eurasian milfoil (ANZECC, 2000).

Unclassified chronic toxicity data for algae and macrophytes were available. Endpoints for the green algae *C. pyrenoidosa* ranged from a growth or cell composition NOEC of 10 mg/L (Fernandez et al., 1984) to a 72 hour IC of 100 mg/L (Maseo et al., 1985). A 32 day IC50 of 40.3 mg/L for root growth was available for the spiked or Eurasian milfoil (Stanley, 1974).

2.3 Summary of Toxicity Data

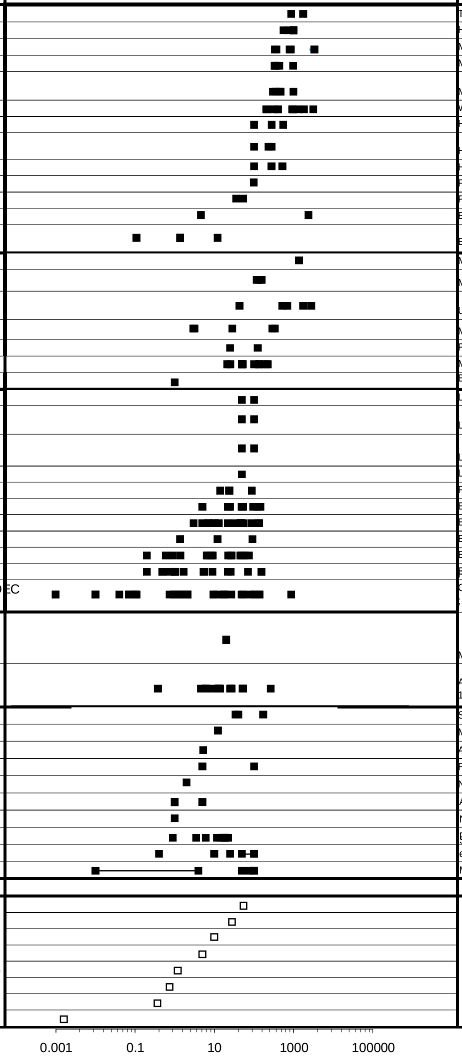
The ranges of toxicity exhibited by aquatic organisms exposed to boron are summarized in Figure 2.

Figure 2 Toxicity ranges exhibited by aquatic organisms exposed to boron

Toxicity Information Considered		Species and Life Stage	Toxicity Endpoint	CONCENTRATION (mg/L)	REF.
Acute	Vertebrates	Toad (*B. vulgaris formosus*) (embryo)	24hr-Mortality and Teratogenesis		Takeuchi, 1958 ; U.S. EPA, 1975
		Chinook salmon (*O. tshawytscha*) (eggs to swim-up fry)	24hr to 96hr-LC50		Hamilton and Buhl, 1990
		Minnow	Various MLD		McKee and Wolf, 1963; NAS, 1973; McKee and Wolf, 1963
		Rainbow trout (*O. mykiss*) (early life stages and adult)	Various LC50s; 7d-EC50 (embryo test); 0.5hr-NOEC		MELP, 1996; Birge and Black, 1977 and Sprague, 1972
		Coho salmon (*O. kisutch*) (swim-up fry and not specified)	24hr to 96hr-LC50		MELP, 1996; Hamilton and Buhl, 1990
		Mosquito fish (*G. afinis*) (adult)	96hr-LC50; 96hr-NOEC; 24hr to 144hr-TLms		Wallen et al., 1957; Birge and Black, 1977
		Bonytail (*G. elegans*) (swim-up fry and juvenile)	96hr-LC50		Hamilton, 1995
		Razorback sucker (*X. texanus*) (swim-up fry and juvenile)	96hr-LC50		Hamilton, 1995
		Colorado squawfish (*P. lucius*) (swim-up fry to juvenile)	96hr-LC50		Hamilton, 1995
		Zebrafish (*D. rerio*) (zygote fertilization to free feeding)	96hr-LOEC (mortality)		Rowe et al., 1998
		Frog (*X. laevis*) (embryo-larval)	4d-LOEC/NOEC (development)		Fort et al., 1999
		Bluegill (*L. macrochirus*)	24hr-LC50; 24hr-TLm		Birge and Black, 1977; Turnbull et al., 1954
		Largemouth bass (*M. salmoides*) (embryo-hatching stages)	3d-LOEC/NOEC (teratogenesis, mortality)		Black et al., 1993
	Invertebrates	Midge (*C. decorus*) (larvae, fourth instar)	48hr-LC50		Maier and Knight, 1991
		Midge (*C. tentans*) (third instar larval)	96hr-LC50		MELP, 1996
		Mosquito larvae (3 species) (pupae, and second and third instar)	48hr-LC100; LC97-99		U.S. EPA, 1975 In Eisler, 1990
		Amphipod (*H. azteca*)	96hr-LC50; 7d-LC50		MELP, 1996; Borgmann *et al*., 2005
		Mosquito larvae (*A. quadrimaculatus*)	25hr to 48hr-Mortality		Fay, 1959 In Butterwick et al., 1989
		Water flea (*D. magna*) (neonates, <24 hr old)	48hr-LC50; LOECs (mortality); Various NOECs		MELP, 1996; Gersich, 1984; Lewis and Valentine, 1981
		Protozoan (*E. sulcatum*)	72hr-TT (cell replication)		Bringmann, 1978
Chronic	Vertebrates	Wood frog (*R. sylvatica*) (blastula lifestage eggs)	13-23d-LOEC/NOEC (reproduction)		Laposata and Dunson, 1998
		Spotted salamander (*A. maculatum*) (blastula lifestage eggs)	38-44d-LOEC/NOEC (reproduction)		Laposata and Dunson, 1998
		Jefferson salamander (*A. jeffersonianum*) (blastula lifestage eggs)	17-25d-LOEC/NOEC (reproduction)		Laposata and Dunson, 1998
		American toad (*B. americanus*) (blastula lifestage eggs)	15-23d-LOEC (reproduction)		Laposata and Dunson, 1998
		Fathead minnow (*P. promelas*) (eggs and fry)	30d to 60d-LOECs/NOECs (growth, mortality)		Proctor and Gamble (unpublished)
		Fowler's toad (*B. fowleri*) (embryo-larval stages)	7d-LOEC; 7d-NOEC; 7d to 7.5d-LC50/LC1		Birge and Black, 1977
		Leopard Frog (*R. pipiens*) (embryo-larval stages)	7d-LOEC/NOEC, 7d to 7.5d-LC50/LC1		Birge and Black, 1977
		Largemouth bass (*M. salmoides*) (embryo-larval stages)	11d-LC50, 11d-LOEC/NOEC (mortality)		Black et al., 1993, Birge and Black, 1981
		Goldfish *(C. auratus)* (embryo larval stages)	7d-LOEC/NOEC; 7d-LC50/LC1		Birge and Black, 1977
		Channel catfish *(I. punctatus)* (embryo larval stages)	9d-LC50, 9d-LOEC/NOEC (mortality), 9d-LC1		Birge and Black, 1977
		Rainbow trout *(O. mykiss)* (eggs, embryos and early life stages)	28d to 32d-LC50, 32d to 60d-LOEC (teratogenesis, mortality), 28d to 87d-NOEC (reproduction, mortality)		Rowe et al., 1998; ANZECC, 2000; Black et al., 1993; Proctor and Gamble (unpublished) ; Birge and Black, 1977; Birge and Black, 1981 ; Wurtz, 1945
	Invertebrates	*(C. decorus) (larvae, fourth instar)*	96hr- LOEC/NOEC (growth)		Maier and Knight, 1991
		Water flea (*D. magna*) (<24 hr old and adult)	21d-MATC, 21d-LC50; Various LOECs/NOECs (growth, reproduction); TT (immobilization)		ANZECC, 2000; MELP, 1996; Gersich, 1984 ; Lewis and Valentine, 1981; MELP, 1996; McKee and Wolf, 1963
	Plants	Spiked or Eurasian watermillfoil (*M. spicatum*)	32d-EC50 (growth), NOEC		Stanley, 1974; ANZECC, 2000
		(*S. capricornutum*) (4-7 d old)	72hr-LOEC, 72hr-NOEC		MELP, 1996
		Chlorella algae (*C. vulgaris*)	NOEC (population growth)		ANZECC, 2000
		Duckweed (L. minor)	Growth inhibition		Frick, 1985
		(M. alterniflourum)	Growth inhibition		Nobel et al., 1983
		(*E. canadensis*)	21d-LC50, NOEC, Growth inhibition		ANZECC, 2000; Nobel et al., 1983
		(R. penicillatus)	Growth inhibition		Nobel et al., 1983
		Duckweed (*S. polyrrhiza*)	10d-LOEC, 10d-EC50, 10d-NOEC (growth)		Davis et al., 2002
		Green Alga *(C. pyrenoidosa)*	LOEC, NOEC (growth, cell division and biomass synthesis)		Sanchez et al., 1982 ; Maeso et al., 1985 ; ANZECC, 2000; Fernandez et al., 1984
		Blue Green Algae (*A. nidulans*)	LOEC, NOEC (photosynthesis, chlorophyll content, growth)		Martinez et al., 1986 ; Martinez et al., 1986 and Mateo et al., 1987

Other Criteria

Quebec Final Acute Value (55 mg/L)
Quebec Acute Guideline (Final Acute Value divided by 2) (28 mg/L)
New York state (10 mg/L)
Quebec Chronic Guideline (5 mg/L)
BC MOE (1.2 mg/L)
U.S. EPA Region IV (0.75 mg/L)
Australia and New Zealand (0.37 mg/L)
U.S. EPA Region VI (0.0016 mg/L)



■	Toxicity endpoints
□	Criteria of other agencies
○	Critical value
LTC	Lethal threshold concentration
TT	Toxicity threshold
TLm	Median tolerance limit

Primary acute toxicity data for vertebrates were available for early life stages of four fish species. Endpoints ranged from a 3 day NOEC (teratogenesis at hatching) of 0.109 mg/L for embryo-hatching stage largemouth bass (Black *et al.*, 1993) to a 7 day EC_{50} (embryo test) of 969 mg/L for rainbow trout (MELP, 1996). Secondary and unclassified toxicity data were similar to the reported primary data with effect concentrations ranging between 4.6 and 3,145 mg/L.

Primary acute toxicity data for invertebrates were available for four species. The 48 hour LC_{50} concentrations ranged from 21.3 mg/L for neonate water fleas (MELP, 1996) to 1,376 mg/L for larval midge (Maier and Knight, 1991). Secondary, unclassified and unacceptable toxicity data were similar to the reported primary data with effect concentrations ranging between 1 and 2,797 mg/L.

Primary chronic toxicity data for vertebrates were available for three fish species. Excluding the outliers identified in Section 2.2, effect concentrations ranged from a 36 day LOEC (mortality) of 1.34 mg/L for embryo-larval rainbow trout to a 32 day LC50 of 138 mg/L for rainbow trout (Black *et al.*, 1993). Lower effect concentrations (0.01 mg/L) for embryo-larval rainbow trout were observed in the unclassified toxicity studies (Birge and Black, 1977).

Primary chronic toxicity data for invertebrates were available for two species. Effect concentrations ranged between a 21 day LOEC (mean brood size) of 13 mg/L to a 21 day LC_{50} of 53.2 mg/L for the water flea (Lewis and Valentine, 1981). Effect concentrations for additional unclassified studies differed from those reported by the primary studies, with a range of <0.38 to ~266 mg/L.

Primary chronic toxicity data were available for 4 to 7 day old green algae (*Selenastrum capricornutum*) (MELP, 1997). The lowest reported effect concentration for algae exposed to boron was a 72 hour LOEC of 12.3 mg/L. Effect concentrations of secondary and unclassified toxicity data ranged from 1 to ~171 mg/L.

Additional factors such as water quality parameters and essentiality may also affect the toxicity of boron to aquatic species. These issues are discussed in Sections 2.4 and 2.5.

2.4 Effects of Water Quality Parameters on Toxicity

The toxicity of many elements depends on the chemical speciation of the dissolved species. Boron was added as several water soluble forms for aquatic toxicity studies (Appendix A) such as boric acid, sodium tetraborate, sodium borate, borax, sodium metaborate and sodium perborate. Birge and Black (1977) conducted a comparative toxicity test of boron administered as borax or boric acid. When the LC_1 and LC_{50} data for all species were combined, there was no statistically significant difference between the toxicity values for boric acid and borax. However, this does not hold true for all water soluble forms of boron. For instance, Turnbull *et al.* (1954) examined the acute toxicity of sodium metaborate and boron trifluoride on bluegill sunfish. The 24 hour TLm (median tolerance limit) for sodium metaborate and boron trifluoride were 4.6 and 2,389 mg/L, respectively (Turnbull *et al.*, 1954). Furthermore, the 24 hour TLm for boric acid and sodium tetraborate were 3,145 and 1,360 mg/L, respectively, for adult female mosquito fish (*Gambusia afinis*). Although there were no statistically significant differences between the aquatic toxicity of boric acid and borax, this may not hold true for other water soluble forms of boron.

The toxicity of metals to aquatic organisms is often modified by water hardness. In general, there does not appear to be any significant interaction between water hardness and boron toxicity (Birge and Black, 1977; Laws, 1981; Hamilton and Buhl, 1990; Maier and Knight, 1991). Birge and Black (1977) investigated the effect of water hardness (at 50 and 200 mg $CaCO_3$/L) on the toxicity of boron to aquatic organisms. When LC_1 and LC_{50} data for all species were combined, there were no statistically significant differences between the values for boric acid and borax. The hardness of the test medium was found to exert an effect on the toxicity of boron to fish; however, this effect was not consistent. For instance, borax exhibited greater toxicity in hard water to embryos and larvae of both goldfish and channel catfish, while embryos and larvae of rainbow trout were more sensitive to borax in soft water. Maier and Knight (1991) examined the interaction of boron and water hardness on the mortality of neonate *Daphnia magna*. No significant interaction was observed between boron toxicity and water hardness, as the mortality (48 hour LC_{50}) associated with boron exposure did not significantly change when water hardness increased from 10.6 to 170 mg/L. British Columbia MELP (1996) found no correlation between hardness and toxicity for coho salmon, rainbow trout and chironomid test outcomes. However, decreasing toxicity with increased hardness was observed for *Daphnia* and *Hyalella* (MELP, 1996). Overall, water hardness does not significantly impact the toxicity of boron to aquatic organisms.

Laws (1981) found that there was no interaction between sulphate and boron in natural aquatic ecosystems.

Several studies have shown that the low-level effects observed in reconstituted laboratory water are not predictive of the much higher effect levels found under natural water exposure conditions (Butterwick *et al.*, 1989; Black *et al.*, 1993). Consistent concentration-related lowest observed effect levels in reconstituted laboratory water range from <0.1 to greater than 18.0 mg/L for rainbow trout (Birge and Black, 1977). The lowest effect concentration for rainbow trout exposed to natural water amended with boron from the Erwin hatchery, Brookville Lake and the Firehole River was 1.0 mg/L; however, ambient concentrations of 0.75 mg/L did not produce significant effects (Black *et al.*, 1993). No effects were observed at measured boron concentrations of 2.1 mg/L administered for 87 days during early life stage trout studies. In addition, a boron concentration of 18 mg/L produced no significant effects when exposure occurred 20 days after egg fertilization and maintained until 60 days post-hatching (Black *et al.*, 1993). Boron concentrations were measured in California streams where viable populations of wild trout were observed (Black *et al.*, 1993). In approximately 88% of the streams, boron was detected at or below 0.5 mg/L. However, in one stream, boron was found at concentrations as high as 13 mg/L (Black *et al.*, 1993). These field observations further support that rainbow trout are less sensitive to natural water boron concentrations than when exposed to boron in laboratory reconstituted water. These variations may be a result of differences in the natural chemical composition of waters from different geographical regions which may modify the toxicity of boron (Black *et al.*, 1993). However, the specific component of the water chemistry responsible for toxicity modification is unknown. It is hypothesized that boron attenuation may occur *via* complexation with organic compounds or adsorption to particulate matter.

2.5 Essentiality and Deficiency

The essentiality of chemicals should be considered during water quality guideline derivation for the protection of aquatic life. Essentiality of an element means that the absence or deficiency of the element results in the impairment of life functions, and that the impairment can be prevented or corrected only by supplementation of physiological levels of the element and not by others. Essential chemicals are different than non-essential chemicals as negative effects on organisms are observed when insufficient levels (*i.e.*, levels below the compensation limit of accumulation / assimilation of the organism) of the chemical are present in the environment. This deficiency varies between organisms, between species, and within species based on respective locale (adaptation). As organisms have adapted to their natural habitat, it can be assumed that the natural background concentrations of essential chemicals at a given locale fulfill the requirements of essentiality to organisms there. Organisms requiring levels of essential chemicals in greater quantities than those naturally present in a particular environment (natural background concentrations) are not expected to be present naturally in this environment to begin with, or if present, would suffer from deficiency not caused by anthropogenic influences.

The effects of boron have been studied on a variety of freshwater fish, amphibians, invertebrates and plants. At lower concentrations, boron has been found to be beneficial to some freshwater organisms. For instance, the addition of 0.4 mg B/L to ponds used for raising carp increased production by 7.6% (Avetisyan, 1983). Furthermore, Fort *et al*. (1999) found that boron was nutritionally essential for the reproduction and development in frogs (*Xenopus laevis*).

Rowe *et al.* (1998) found that the shape of the dose-response curve in rainbow trout (*Oncorhyncus mykiss*) and zebrafish follows the U-shaped adverse response of an essential nutrient. This shape reflects effects of exposure to boron concentrations below the level to meet physiological requirements and toxic effects due to exposure to high concentrations of boron that exceed the threshold for safety. For rainbow trout embryos, chronic exposures below 9.7×10^{-2} mg/L impaired embryonic growth. In addition, zebrafish exposed to boron concentrations below 2.2×10^{-3} mg/L experienced zygote death (Rowe *et al*., 1998). The theory regarding boron essentiality suggested by the results of Rowe et al. (1998) may explain why the Birge and Black studies have consistently found very low concentration toxicity levels for boron for a variety of aquatic species.

In order to prevent adverse health effects to organisms caused by a deficiency of essential chemicals, recommended threshold levels for these chemicals should not fall below the level required by the organism to remain healthy.

3.0 BIOACCUMULATION

The bioaccumulation and biomagnification of boron in the aquatic environment is not clearly understood (Moss and Nagpal, 2003). In general, the literature suggests that aquatic environments are not likely to experience boron biomagnifications, however, there is evidence of bioaccumulation (Wren *et al*., 1983; Butterwick *et al.*, 1989). Boron has been shown to accumulate in aquatic plants (Wren *et al*., 1983; Saiki *et al*., 1993), although this is species specific. Fernandez *et al.* (1984) examined the bioaccumulation of boron in green alga (*Chlorella pyrenoidosa*). After seven days, the bioconcentration factor (BCF) for three concentration levels ranged from four to five. In a study conducted by Davis *et al*. (2002), duckweed (*Spirodella polyrrhiza*) did not remove significant amounts of boron from the treatment solutions. However, Glandon and McNabb (1978) found that duckweed (*Lemna minor*) did bioaccumulate boron compared to other hydrophytes (*e.g.*, *Ceratophyllum demersum*). A curvilinear relationship was observed between ambient boron concentrations and concentrations in the plant tissues, suggesting that both active and passive transport of boron across plant root membranes occurs in this species. Frick (1985) found that pH affected the bioaccumulation of boron by duckweed (*Lemna minor*).

Despite a tendency to accumulate in plants and algae, boron bioaccumulation by invertebrates and fish has been shown to be lower (Saiki et al 1993), and boron does not appear to biomagnify through the food chain (Wren *et al*., 1983; Saiki *et al*., 1993). The BCFs for boron in marine and freshwater plants, fish and invertebrates were estimated to be less than 100 (Thompson *et al*., 1972). Experimental BCFs for fish have ranged between 52 and 198 (Tsui and McCart, 1981). In the marine environment, Thompson *et al.* (1976) found no evidence of boron bioaccumulation in sockeye salmon (*Oncrohynchus nerka)* tissues or pacific oyster (*Crassostrea gigas*). In both instances, tissue boron concentrations approximated boron concentrations in the test water (Thompson *et al*., 1976). In the oyster, tissue concentrations returned to background levels by the 71st day of the study after boron exposure ceased, indicating a fairly rapid clearance of boron. Furthermore, a study conducted by Suloway *et al.* (1983) examined the bioaccumulation potential of the components of coal fly ash extract in fathead minnows (*Pimephales promelas*) and green sunfish (*Lepomis cyanellus*). The BCF for boron was 0.3 for both species. These BCF values suggest that boron does not significantly bioconcentrate or biomagnify in the aquatic environment.

4.0 IMPACT ON TASTE AND ODOUR OF WATER AND FISH TAINTING

No information on the impact of boron on the taste and odour of water or fish tainting was available. Neither Health Canada (1990) nor WHO (2003) derived a drinking water quality guideline for boron based on this endpoint.

5.0 MUTAGENICITY

Boron and its compounds are not considered mutagenic in either bacterial or mammalian systems.

In a *Salmonella typhimurium*-mammalian microsome mutagenicity assay, boron did not enhance or inhibit the activity of benzo[a]pyrene, a known mutagen (Benson *et al*., 1984). Boric acid and borax were not mutagenic in *Salmonella typhimurium* with or without rat or hamster S9 fraction (Haworth *et al*., 1983; Benson *et al*., 1984; NTP, 1987; Steward, 1991). Boric acid was not mutagenic, or produced equivocal results, in the streptomycin-dependant *Escherichia coli* Sd-4 assay (Demerec *et al*., 1951; Iyer and Szybalski, 1958; Szybalski, 1958). Sodium perborate was shown to interact with DNA in an *Escherichia coli* Pol A assay, presumably by being converted to hydrogen peroxide (Rosenkranz, 1973). A single study (Odunola, 1997) found that boric acid induced *B*-galactosidase synthesis (a response to DNA lesions) in *E. coli* PQ37 (SOS chromotest) with and without metabolic activation.

Results in mammalian systems for mutagenicity were all negative (U.S. EPA, 2004). Boric acid did not induce unscheduled DNA synthesis in primary cultures of male rat hepatocytes (Bakke, 1991). Refined borax, crude borax ore and kermite ore were not mutagenic in V79 Chinese hamster cells, mouse embryo fibroblasts or diploid human foreskin fibroblasts (Landolph, 1985).

In addition, other tests have shown that boric acid does not induce chromosomal aberrations or sister chromatid exchanges in Chinese hamster ovary cells (NTP, 1987). Forward mutations in mouse lymphoma cells were not induced by boric acid with or without rat liver S9 (NTP, 1987; McGregor *et al*., 1988). In addition boric acid did not induce mutations at the thymidine kinase locus in mouse lymphoma cells in the presence or absence of rat liver activation system (Rudd, 1991). Finally, boric acid did not induce chromosomal or mitotic spindle abnormalities in bone marrow erythrocytes in the micronucleus assay in Swiss-Webster mice (O'Loughlin, 1991).

6.0 DERMAL AND OTHER EFFECTS

Absorption of boron is poor through intact skin, but is much greater through damaged skin (WHO, 2003). Little information was found on the protection of recreational water uses based on public health concerns, wildlife protection, toxicant interactions or sediment quality. Australia and New Zealand Environment and Conservation Council (ANZECC, 2000) have a guideline for protection of recreational water uses and aesthetics of 1 mg/L, although the basis of this guideline was not provided.

7.0 METHOD DETECTION LIMITS

The Ontario Ministry of the Environment uses a method to measure trace metals (boron) in water that has been certified by the Canadian Association for Environmental Analytical Laboratories (CAEAL). The method (E3474) determines the concentration of trace metals in surface and groundwater by dynamic reaction cell (DRC) using inductively coupled plasma-mass spectrometry (ICP-MS) (R. Moody, Manager Spectroscopy Section, Laboratory Services Branch, Ontario Ministry of the Environment, personal communication). The current MOE laboratory detection limit in water is 0.2 µg L^{-1} or 0.0002 mg L^{-1}. Environment Canada's National Laboratory for Environmental Testing (NLET) analyzes for trace metals (boron) in water using ICP-MS with a method detection limit of 0.5 µg L^{-1} or 0.0005 mg L^{-1} (J. Carrier, Inorganics Analyst, NLET, Environment Canada, personal communication). Various analytical methods are available to accurately detect boron levels in water ranging from 0.01 mg L^{-1} to 10 mg L^{-1} (Health Canada, 1990).

8.0 DERIVATION OF SPECIES SENSITIVITY DISTRIBUTIONS

Species sensitivity distributions (SSDs) represent the variation in sensitivity of species to a substance by a statistical or empirical distribution function of responses for a sample of species. The basic assumption of the SSD concept is that the sensitivities of a set of species can be described by some distribution, usually a parametric sigmoidal cumulative distribution function. The use of SSDs has become common in ecological risk assessment as well as environmental quality guideline development. In 2007, the Canadian Council of Ministers of the Environment (CCME) established a new protocol for deriving water quality guidelines for the protection of aquatic life. Canadian Water Quality Guidelines for the Protection of Aquatic Life (CWQGs-PAL) are nationally accepted threshold values for substances and other attributes (such as pH and temperature) in water. These values are determined such that no adverse toxic effects are expected in aquatic plants and animals. The guidelines are management tools constructed to ensure that anthropogenic stresses, such as the introduction of toxic substances, do not result in the degradation of Canadian waters. The 2007 protocol for the derivation of CWQGs-PAL now provides three options for guideline development, all dependent on the quantity and quality of toxicity data available. The first, and recommended, guideline derivation method involves modeling the cumulative species sensitivity distribution (SSD) with estimating the 95% confidence interval. The guideline is defined as the intercept of the 5th percentile of the species sensitivity distribution (CCME, 2007) and is interpreted as protecting 95% of species. This level of protection ensures that aquatic community structure and function is maintained. SSD derived guidelines are referred to as Type A guidelines. If data are inadequate to derive a Type A guideline, then either a Type B1 of B2 guideline can be set, where an assessment or uncertainty factor is applied to the lowest effect concentration found in the scientific literature. The minimum data requirements for setting either a Type A, B1 or B2 guideline can be found in the CCME (2007) protocol document. The Type B1 and B2 guidelines are a modified version of the method traditionally used to derive Canadian Water Quality Guidelines for the Protection of Aquatic Life decribed in the 1991 CCME protocol. In the case of boron, suitable short-term and long-term datasets were provided for the development of a Type A guideline. Freshwater SSDs for freshwater biota were derived for both exposure durations following the CCME Protocol for the Derivation of Water Quality Guidelines for the Protection of Aquatic Life (CCME, 2007). Results may be used in accordance with the protocol to derive guideline values for boron.

To generate the short-term and long-term SSDs primary, secondary and unclassified toxicity data were included; however, datapoints classified as unacceptable were excluded. When multiple data points or effects (*e.g.*, growth, mortality, reproduction) were available for the same species professional judgment was utilized to select a representative species effect concentration (*e.g.*, lowest value or geomean). Using a customized Microsoft Excel-based software package, SSD Master Version 2.0, a total of five cumulative distribution functions were fit to the data using regression techniques. Model fit was assessed using statistical and graphical techniques. The best model was selected based on goodness-of-fit and model feasibility. Model assumptions were verified graphically. The concentration of boron in freshwater at which 5% of species are predicted to be affected was determined for both short-term and long-term scenarios with 95% confidence intervals on the mean (expected) value.

The Generalized Linear Model (GLiM) framework described by Kerr and Meador (1996) and Bailer and Oris (1997) was used as the modelling framework to derive the short- and long-term SSDs. The framework involves using link functions to transform metrics and assigning appropriate error distributions (*e.g.*, binomial distribution for quantal responses). Each species for which appropriate toxicity data were available was ranked according to sensitivity (from lowest to highest value), and its centralized position on the SSD (Hazen plotting position) was determined using the following standard equation (Aldenberg *et al.*, 2002; Newman *et al.*, 2002):

$$\text{Hazen Plotting Position} = \frac{i - 0.5}{N}$$

where:

i = the species rank based on ascending toxicity values
N = the total number of species included in the SSD derivation

8.1 Short-term SSD Derivation

Short-term exposure benchmark concentrations are derived using severe effects data (such as lethality or immobilization) of defined short-term exposure periods (24-96h). These guidelines identify estimators of severe effects to the aquatic ecosystem and are intended to give guidance on the impacts of severe, but transient, situations (e.g., spill events to aquatic receiving environments and infrequent releases of short-lived/nonpersistent substances). Short-term benchmark concentrations *do not* provide guidance on protective levels of a substance in the aquatic environment, as short-term benchmark concentrations are levels which *do not* protect against adverse effects.

The minimum data requirements for the development of a short-term Type A (SSD-derived) benchmark were met, and these are listed in Table 8-1.

Table 8- 1 Minimum Data Set Requirements for the Gerneration of a Short-Term Freshwater Benchmark Concentration

Toxicity tests required for the generation of a short-term SSD, broken out as follows:
Fish: 3 tests on 3 different species including 1 salmonid, 1 non-salmonid.
Invertebrates: 3 tests on 3 different species including 1 planktonic crustacean, 2 others. For semi-aquatic invertebrates, the life stages tested must be aquatic. It is desirable, but not necessary, that one of the aquatic invertebrate species be either a mayfly, caddisfly, or stonefly.
Plant/Algae: None (for non-phytotoxic substances), 2 (for phytotoxic substances).
Toxicity data for **amphibians** are highly desirable, but not necessary. Data must represent fully aquatic stages.
Acceptable endpoints for acute guidance: LC/EC50 (severe effects) Note: Primary or secondary data are acceptable.

A total of 13 data points (all LC_{50} values) were used in the derivation of the benchmark concentratoni (Table 8-2). These 13 data points were retrieved from toxicity studies meeting the requirements for primary and secondary data, according to CCME (2007) protocol. Intra-species variability was accounted for by taking the geometric mean of the studies considered to represent the most sensitive lifestage and endpoint. Each data point was ranked according to sensitivity, and its centralized distribution on the species sensitivity distribution (SSD) was determined using the Hazen plotting position (estimate of the cumulative probability of a data point). The plotting positions are treated as observed proportions of species affected. These positional rankings, along with their corresponding LC_{50} values, were used to derive the SSDs.

Table 8- 2 Short-term LC_{50}s for species exposed to boron in freshwater

Rank	*Scientific Name*	*Common Name*	*Endpoint*	*LC_{50} (mg B/L)*	*Data Quality*	*Hazen Plotting Position*	*Reference*
1	*Lepomis macrochirus*	Bluegill	Mortality	4.6	S	0.04	Turnbull et al., 1954
2	*Pimephales promelas*	Fathead minnow	Mortality	64.3	P	0.12	MOE, 2007
3	*Daphnia magna*	Water flea	Mortality	101.2	Grouped P*, P, S	0.19	Maier & Knight, 1991; MOE 2007; MELP 1996; Lewis & Valentine 1981; Gersich, 1984
4	*Chironomus*	Midge	Mortality	136.7	Grouped	0.27	MELP, 1996

Rank	***Scientific Name***	***Common Name***	***Endpoint***	***LC$_{50}$ (mg B/L)***	***Data Quality***	***Hazen Plotting Position***	***Reference***
	tentans				P*		
5	*Hyalella azteca*	Freshwater shrimp	Mortality	141.1	Grouped P*	0.35	MELP, 1996
6	*Xyrauchen texanus*	Razorback sucker	Mortality	233	S	0.42	Hamilton, 1995
7	*Ptychocheilus lucius*	Colorado squawfish	Mortality	279	S	0.50	Hamilton, 1995
8	*Gila elegans*	Bonytail	Mortality	280	S	0.58	Hamilton, 1995
9	*Oncorhynchus mykiss*	Rainbow trout	Mortality	351.7	Grouped P*, P	0.65	MELP, 1996; MOE 2007
10	*Oncorhynchus kisutch*	Chinook salmon	Mortality	372.9	Grouped P*	0.73	MELP, 1996
11	*Oncorhynchus tshawytscha*	Coho salmon	Mortality	566	S	0.81	Hamilton and Buhl, 1990
12	*Gambusia affinis*	Mosquitofish	Mortality	632	S	0.88	Wallen et al., 1957
13	*Chironomus decorus*	Midge	Mortality	1376	P	0.96	Maier and Knight, 1991

Data Quality:
S = Secondary; P = Primary; P* = Primary as defined by Moss and Nagpal (2003); S* = Secondary as defined by Moss and Nagpal (2003)
Grouped Indicates that the geomean of multiple values was used to calculate the effect concentration

The values reported in Table 8-2 range from a 24h-LC50 of 4.6 mg/L for the Bluegill sunfish, *Lepomis macrochirus (*Turnbull et al., 1954), to a 48-h LC50 of 1376 mg/L for the midge, *Chironomus decorus* (Maier and Knight, 1991). Geometric mean values were calculated for *Daphnia magna*, *Chironomus tentans*, *Hyalella azteca*, *Oncorhynchus mykiss*, and *Oncorhynchus kisutch* (Table 8-3). Effect concentrations reported for the remaining species were taken from single studies.

Table 8- 3 Studies Used to Derive Geometric Means for Short-Term Data

Organism	**Endpoint**	**Effect Concentration (mg/L)**	**Geometric Mean (mg/L)**	**Reference**
Daphnia magna (Water flea)	48-h LC$_{50}$	141 165 21.3 52.4 139.2 226 133	101.2	Maier & Knight, 1991; MOE 2007; MELP 1996; Lewis & Valentine 1981; Gersich, 1984
Chironomus tentans (Midge)	96-h LC$_{50}$	118 137.7 157.3	136.7	MELP, 1996
Hyalella azteca (Freshwater shrimp)	96-h LC$_{50}$	28.9 291.3 333.6	141.1	MELP, 1996
Oncorhynchus	96-h LC$_{50}$	275	351.7	MELP, 1996;

mykiss (Rainbow trout)		336 379.6 436.2		MOE 2007
Oncorhynchus kisutch (Chinook salmon)	96-h LC_{50}	304.1 357.4 477.1	372.9	MELP, 1996

Five cumulative distribution functions (normal, logistic, Gompertz, Weibull, and Fisher-Tippett) were fit to the data, both in arithmetic space (no transformation of LC_{50} values) and log space (log transformed LC_{50} values) using regression methods. Model fit was assessed using statistical and graphical techniques. The best model was selected based on consideration of goodness-of-fit test and model feasibility. Model assumptions were verified graphically and with the use of statistical tests.

Of the ten models tested, the log-Gompertz model fit the data best (Figure 3). The Anderson-Darling Goodness of Fit test statistic (A^2) was 0.304 (P-value > 0.10). The equation of the fitted log-Gompertz model is of the form:

$$y = 1 - e^{-e^{\left(\frac{x-\mu}{\delta}\right)}}$$

Where x is the log (concentration) and y is the proportion of species affected. For the fitted model, $\mu = 2.5319$ and $\delta = 0.3609$. Summary statistics for the short-term SSD are presented in Table 8-4. The 5^{th} percentile on the short-term SSD is 29 mg/L. The lower fiducial limit (5%) on the 5^{th} percentile is 15 mg/L, and the upper fiducial limit (95%) on the 5^{th} percentile is 55 mg/L. The benchmark concentration is defined as the 5^{th} percentile on the SSD.

Therefore, the short-term exposure benchmark concentration indicating the potential for severe effects (e.g. lethality or immobilization) to sensitive freshwater life/marine life during transient events is 29 mg/L.

Table 8- 4 Short-term Concentration for Boron Resulting from the SSD Method

	Concentration
SSD 5th percentile	29 mg/L
Lower 95% confidence limit	15 mg/L
Upper 95% confidence limit	55 mg/L

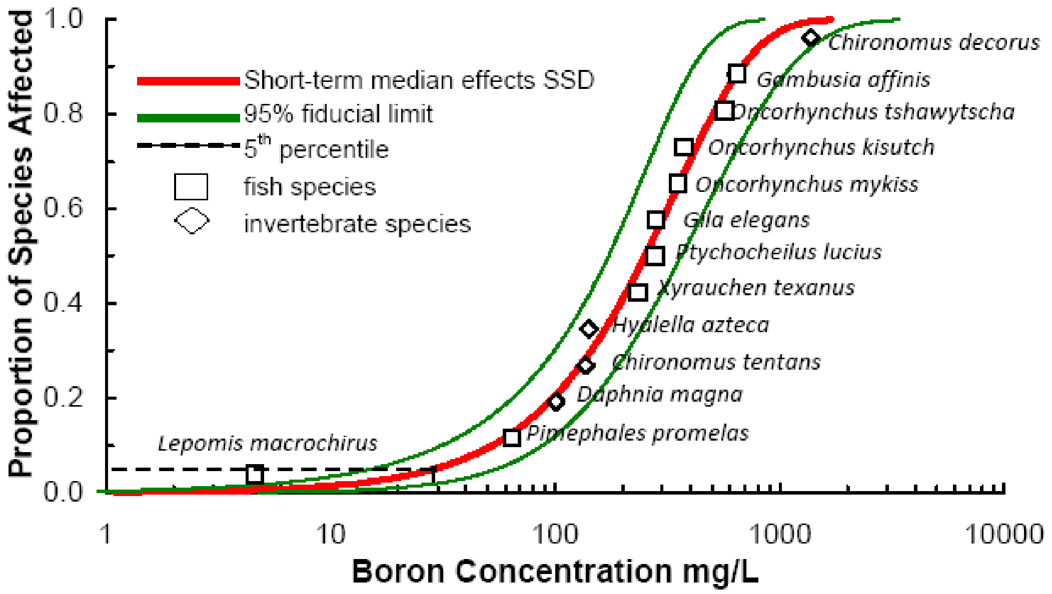


Figure 3 **SSD for boron in freshwater derived by fitting the log-Gompertz model to the logarithm of acceptable short-term LC_{50}s of thirteen aquatic species versus Hazen plotting position (proportion of species affected).**

8.2 Long-term SSD Derivation

Long-term exposure guidelines identify benchmarks in the aquatic ecosystem that are intended to protect all forms of aquatic life for indefinite exposure periods (≥7d exposures for fish and invertebrates, ≥24h exposures for aquatic plants and algae).

The minimum data requirements for the development of a long-term Type A (SSD-derived) guideline were met, and these are listed in Table 8-5.

Table 8- 5 Minimum Data Set Requirements for the Generation of a long-term freshwater CWQG

Toxicity tests required for the generation of a long-term SSD, broken out as follows:
Fish: 3 tests on 3 different species including 1 salmonid, 1 non-salmonid.
Invertebrates: 3 tests on 3 different species including 1 planktonic crustacean, 2 others. For semi-aquatic invertebrates, the life stages tested must be aquatic. It is desirable, but not necessary, that one

of the aquatic invertebrate species be either a mayfly, caddisfly, or stonefly.
Plant/Algae: At least one study on a freshwater vascular plant or freshwater algal species (for non-phytotoxic substances), 3 studies (for phytotoxic substances)
Toxicity data for **amphibians** are highly desirable, but not necessary. Data must represent fully aquatic stages.
Acceptable endpoints for chronic guidance: Most appropriate ECx/ICx representing a no-effects threshold > EC10/IC10 > EC11-25/IC11-25 > MATC > NOEC > LOEC > EC26-49/IC26-49 > nonlethal EC50/IC50. Note: Primary or secondary data are acceptable.

A total of 28 data points (NOEC, EC_{10}, MATC and LOEC data) were used in the derivation of the long-term guideline (Table 4-2). Toxicity studies meeting the requirements for primary and secondary data, according to CCME (2007) protocol. Intra-species variability was accounted for by taking the geometric mean of the studies considered to represent the most sensitive lifestage and endpoint. Each data point was ranked according to sensitivity, and its centralized distribution on the species sensitivity distribution (SSD) was determined using the Hazen plotting position (estimate of the cumulative probability of a data point). The plotting positions are treated as observed proportions of species affected. These positional rankings, along with their corresponding no-effects and low-effects values, were used to derive the SSDs.

Insufficient EC_{10} (one data-point) and EC_{10-25} (no data) no-effect toxicity data were available to construct the SSD, therefore MATC and NOEC endpoints were predominantly used (in addition to the single EC_{10} data-point). With respect to low effect data, insufficient EC_{20} or EC_{20-25} low-effect toxicity data were available, therefore LOEC endpoints were used.

Table 8- 6 Long-term low effects and no effects concentrations for species exposed to boron in freshwater

Rank	Scientific Name	Common Name	Endpoint	**Effective Concentration** (mg B/L)	Data Quality	Hazen Plotting Position	Reference
1	*Elodea canadensis*	American Waterweed	(NOEC)	1.0	S	0.01	ANZECC, 2000
2	*Spirodella polyrrhiza*	Duckweed	Frond production (10 d, MATC)	1.8	Grouped S	0.04	Davis et al., 2002
3	*Chlorella pyrenoidosa*	Green algae	Growth or cell composition (NOEC)	2.0	Grouped S	0.07	ANZECC, 2000; Fernandez et al., 1984
4	*Oncorhynchus mykiss*	Rainbow trout	Embryo survival at 60-d post-hatch (87 d, NOEC)	2.1	P	0.13	Black et al., 1993
5	*Ictalurus punctatus*	Channel catfish	(9 d, MATC)	2.4	Grouped S	0.16	Birge and Black, 1977
6	*Phragmites australis*	Common reed	Growth (4-month, NOEC)	4.0	S	0.19	Bergmann 1995
7	*Micropterus salmoides*	Largemouth bass	(11 d, MATC)	4.1	Grouped P	0.21	Black et al., 1993
8	*Chlorella vulgaris*	Green algae	Population growth (NOEC)	5.2	S	0.24	ANZECC, 2000
9	*Daphnia magna*	Water flea	Reproduction (NOEC)	6.0	S	0.27	ANZECC, 2000
10	*Opercularia bimarginata*	Unknown (Protozoa?)	Growth, reproduction (72-h NOEC)	10.0	S	0.33	Guhl 1992 (German), In Dyer 2001
11	*Brachydanio rerio*	Zebrafish	Mortality, growth, condition (34-d MATC)	10.0	S	0.36	Hooftman et al, 2000
12	*Selenastrum capricornutum*	Green algae	LOEC (72 hr)	12.3	P*	0.41	MELP, 1997 In Moss and Nagpal, 2003
13	*Ceriodaphnia dubia*	Water flea	Growth, reproduction (14-d MATC)	13.4	S	0.44	Hickey, 1989
14	*Entosiphon sulcatum*	Zooplankton	Growth (72-h NOEC)	15.0	S	0.47	Guhl 1992 (German), In Dyer 2001
15	*Carassius auratus*	Goldfish	(7 d, MATC)	15.6	Grouped S	0.50	Birge and Black, 1977
16	*Pimephales promelas*	Fathead minnow	Growth reduction (30 d, MATC)	18.3	Grouped S	0.53	Proctor and Gamble (unpublished) In Butterwick *et al.*, 1989 In Moss and Nagpal, 2003
17	*Chironomus decorus*	Midge	Growth (96-h NOEC)	20.0	S	0.59	Maier and Knight, 1991 In Dyer, 2001
18	*Paramecium caudatum*	Ciliate	Growth, reproduction (72-h NOEC)	20.0	S	0.61	Guhl 1992 (German), In Dyer 2001
19	*Rana pipiens*	Leopard frog	(7 d MATC)	20.4	Grouped S	0.56	Birge and Black, 1977 In

							Butterwick et al., 1989 and Eisler, 1990 In Moss and Nagpal, 2003
20	*Scenedesmus subspicatus*	Green algae	Growth (96-h EC 10)	30.0	S	0.70	Guhl 1992 (German), In Dyer 2001
21	*Myriophyllum spicatum*	Spiked or Eurasian water milfoil	(NOEC)	34.2	S	0.73	ANZECC, 2000
22	*Bufo fowleri*	Fowler's toad	(7 d, MATC)	48.6	S	0.79	Birge and Black, 1977
23	*Anacystis nidulans*	Blue-green algae	Growth or organic constituents (NOEC)	50.0	S	0.81	Martinez et al., 1986
24	*Bufo americanus*	American toad	proportion of eggs hatching (15-23 d, LOEC, 43% decrease compared to controls)	50.0	S	0.84	Laposata and Dunson, 1998
25	*Lemna minor*	Duckweed	Growth (7-d NOEC)	60.0	S	0.87	Wang, 1986
26	*Ambystoma jeffersonianum*	Jefferson's salamander	Proportion of deformed hatchlings (17-25 d, MATC increase in deformities compared to controls)	70.7	Grouped S	0.90	Laposata and Dunson, 1998
27	*Ambystoma maculatum*	Spotted salamander	Proportion of deformed Hatchlings (38-44 d, MATC, increase in deformities compared to controls)	70.7	Grouped S	0.93	Laposata and Dunson, 1998
28	*Rana sylvatica*	Wood frog	Proportion of eggs hatched (13-23 d, MATC)	70.7	Grouped S	0.99	Laposata and Dunson, 1998

Data Quality:
S = Secondary; P = Primary; P* = Primary as defined by Moss and Nagpal (2003); S* = Secondary as defined by Moss and Nagpal (2003); ? = Unclassified toxicity data classified as secondary quality by default (proprietary information, original publication could not be obtained)
Grouped Indicates that the geomean of multiple values was used to calculate the effect concentration

The values reported in Table 8-6 range from a NOEC of 1.0 mg/L for the American waterweed, *Elodea canadensis (*ANZECC, 2000), to a 13-22 d MATC of 70.7 mg/L for the Wood frog, *Rana sylvatica* (Laposata and Dunson, 1998). Geometric mean values were calculated for *Spirodella polyrrhiza, Clorella pyrenoidosa, Ictalurus punctatus, Micropterus salmoides, Carassius auratus, Pimephales promelas, Rana pipiens, Ambystoma jeffersonianum, Ambystoma maculatum,* and *Rana sylvatica* (Table 8-7). Effect concentrations reported for the remaining species were taken from single studies.

Table 8- 7 Studies Used to Derive Geometric Means for Long-Term Data

Organism	**Endpoint**	**Effect Concentration (mg/L)**	**Geometric Mean (mg/L)**	**Reference**
Spirodella polyrrhiza	10-d NOEC 10-d LOEC	0.9 3.5	1.8	Davis et al., 2002

Organism	**Endpoint**	**Effect Concentration (mg/L)**	**Geometric Mean (mg/L)**	**Reference**
(Duckweed)				
Chlorella pyrenoidosa (Green algae)	14-d NOEC 14-d NOEC	0.4 10	2.0	ANZECC, 2000; Fernandez et al., 1984
Ictalurus punctatus (Channel catfish)	9-d NOEC 9-d NOEC 9-d NOEC 9-d NOEC 9-d LOEC 9-d LOEC 9-d LOEC 9-d LOEC	0.49 0.75 1.01 9 1 1.04 5.42 25.9	2.4	Birge and Black, 1977
Micropterus salmoides (Largemouth bass)	11-d NOEC 11-d LOEC	1..39 12.17	4.1	Black et al., 1993
Carassius auratus (Goldfish)	7-d NOEC 7-d NOEC 7-d NOEC 7-d NOEC 7-d LOEC 7-d LOEC 7-d LOEC 7-d LOEC	6.8 8.53 9.2 26.5 8.33 22.5 27.33 48.75	15.6	Birge and Black, 1977
Pimephales promelas (Fathead minnow)	30-d NOEC 30-d LOEC	14 24	18.3	Proctor and Gamble (unpublished) In Butterwick *et al.*, 1989 In Moss and Nagpal, 2003
Rana pipiens (Leopard frog)	7-d NOEC 7-d NOEC 7-d NOEC 7-d NOEC 7-d LOEC 7-d LOEC 7-d LOEC 7-d LOEC	7.04 7.04 32.5 45.7 9.6 10.5 47.5 86	20.4	Birge and Black, 1977 In Butterwick et al., 1989 and Eisler, 1990 In Moss and Nagpal, 2003
Ambystoma jeffersonianum (Jefferson's Salamander)	17-25 d NOEC 17-25d LOEC	50 100	70.7	Laposata and Dunson, 1998
Ambystoma maculatum (Spotted salamander)	38-44 d NOEC 38-44 d LOEC	50 100	70.7	Laposata and Dunson, 1998

Organism	**Endpoint**	**Effect Concentration (mg/L)**	**Geometric Mean (mg/L)**	**Reference**
Rana sylvatica (Wood frog)	13-23 d NOEC 13-23 d LOEC	50 100	70.7	Laposata and Dunson, 1998

Five cumulative distribution functions (normal, logistic, Gompertz, Weibull, and Fisher-Tippett) were fit to the data, both in arithmetic space (no transformation of LC_{50} values) and log space (log transformed LC_{50} values) using regression methods. Model fit was assessed using statistical and graphical techniques. The best model was selected based on consideration of goodness-of-fit test and model feasibility. Model assumptions were verified graphically and with the use of statistical tests.

Of the ten models tested, the log-Normal distribution function (with a mean [μ] of 1.1443 and a standard deviation of [σ] of 0.5984] fit the data best (Figure 4). The Anderson-Darling Goodness of Fit test statistic (A^2) was 0.436 (P-value > 0.10). The equation of the fitted log-Gompertz model is of the form:

$$y = \Phi \left(\frac{x - 1.1443}{0.5984} \right)$$

Where x is the log (concentration) and y is the proportion of species affected, and Φ is the symbol representing normal distribution. Summary statistics for the long-term SSD are presented in Table 8-8. The 5th percentile on the short-term SSD is 1.5 mg/L. The lower fiducial limit (5%) on the 5th percentile is 1.2 mg/L, and the upper fiducial limit (95%) on the 5th percentile is 1.7 mg/L. The CWQGPAqL is defined as the 5th percentile on the SSD.

The long-term exposure CWQG for the protection of freshwater life is 1.5 mg/L.

Table 8- 8 Long-term CWQG for Boron Resulting from the SSD Method

	Concentration
SSD 5th percentile	1.5 mg/L
Lower 95% confidence limit	1.2 mg/L
Upper 95% confidence limit	1.7 mg/L

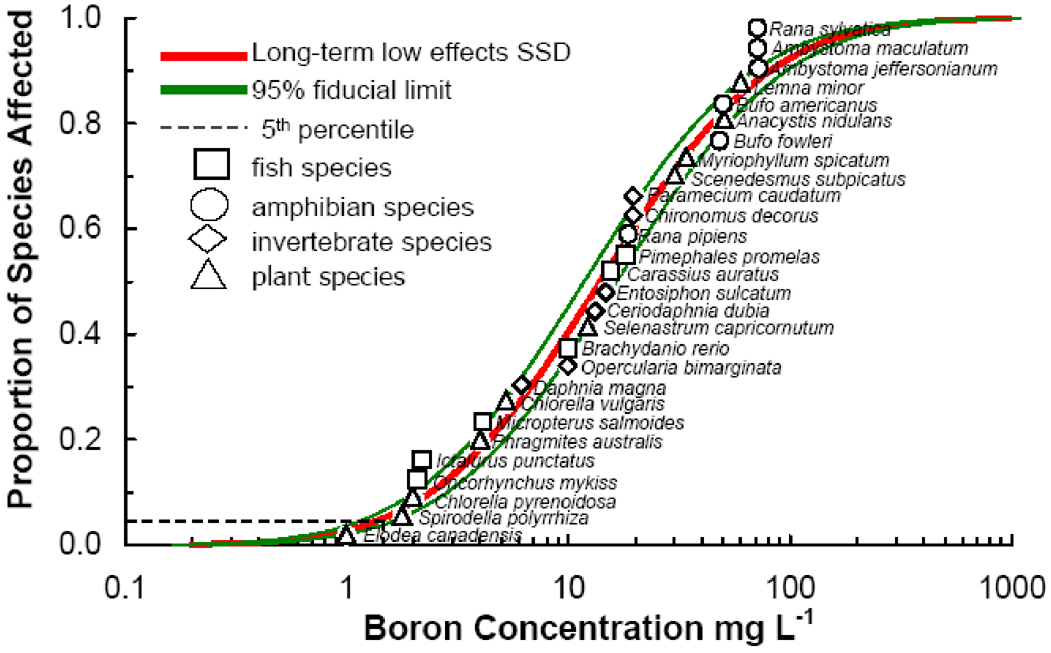


Figure 4 **SSD for boron in freshwater derived by fitting the log-Normal model to the logaritm of acceptable long-term no- and low-effect endpoints for twenty-eight aquatic species versus Hazen plotting position (proportion of species affected)**

Concentrations of boron in Canadian surface waters ranged from 0 to 2.58 mg/L total, 0.0001 to 0.951 mg/L extractable, and 0.0001 to 2.71 mg/L dissolved (Table 2-6). Total boron concentrations were not available for Nova Scotia, however, the maximum measured extractable boron concentration was 0.951 mg/L, which came from one river sample. This sample does not exceed the long-term WQGPAqL of 1.5 mg total boron / L. In the case of Nova Scotia, freshwater surface waters may be under the influence of marine water, which is higher in boron. Total boron concentrations exceeded the long-term WQGPAqL of 1.5 mg/L in Saskatchewan (maximum total boron measured was 2.58 mg/L) and in the Northwest Territories (maximum total boron measured was 2.3 mg/L). In the case of Saskatchewan and the Northwest Territories, these areas may be under the influence of natural boron mineral deposits. No measured surface water concentrations exceeded the short-term WQGPAqL of 29 mg/L.

In order to prevent adverse health effects to organisms caused by a deficiency of essential chemicals, recommended threshold levels for boron should not fall below the level required by the organism to remain healthy. Rowe *et al.* (1998) found that rainbow trout and zebrafish embryos experienced adverse effects at boron concentrations below 9.7×10^{-2} mg/L and 2.2×10^{-3} mg/L, respectively. Therefore, the proposed short-term benchmark concentration and long-term WQGPAqL meet the minimum boron requirements for both species.

9.0 RESEARCH NEEDS

The toxicity of many elements depends on the chemical speciation of the dissolved species. Boron was added as several water soluble forms for aquatic toxicity studies such as boric acid, sodium tetraborate, sodium borate, borax, sodium metaborate and sodium perborate. Although there were no statistically significant differences between the aquatic toxicity of boric acid and borax to aquatic species (Birge and Black, 1977), this may not hold true for other water soluble forms of boron. For example, metaborate releases hydrogen peroxide upon mixing with water, so the aquatic toxicity of this form of boron is know to be different (Guhl 1992) than the more environmentally relevant forms of boron, being undissociated boric acid and borate. Since the pKa of boric acid is 9.2, boric acid is the predominant form of boron in aquatic environments. Additional studies may be conducted to determine if the form of boron utilized during aquatic toxicity testing affects the toxicity of boron.

Several studies have shown that the low-level effects observed in reconstituted laboratory water are not predictive of the much higher effect levels observed under natural water exposure conditions (Butterwick *et al.*, 1989; Black *et al*., 1993). These variations may be a result of differences in the natural chemical composition of waters from different geographical regions which may modify the toxicity of boron (Black *et al.*, 1993). Further studies investigating modifiers of boron aquatic toxicity are recommended.

10.0 OBJECTIVES OF OTHER AGENCIES

Moss and Nagpal (2003) report that the South African national boron criterion for coldwater-adapted species is 0.01 mg/L for acute effects (acute effect value or AEV) and 0.001 mg/L for chronic effects (chronic effect value or CEV) (Roux *et al.*, 1996). However, these values were not identified in the South African water quality guidelines (1996). South Africa established livestock watering and irrigation guidelines for boron of 0 to 5 mg/L and 0 to 0.5 mg/L, respectively (Republic of South Africa, 1996).

Australia and New Zealand adopted a freshwater high reliability trigger value for boron of 0.37 mg/L using the statistical distribution method at 95% protection (ANZECC, 2000). This was calculated using screened chronic freshwater data (around 30 points) from five taxonomic groups. Aquatic toxicity was expressed as NOEC equivalents or were adjusted to NOECs by dividing by factors depending on the endpoints (NOEC = MATC/2, LOEC/2.5 or E(L)C50/5) (ANZECC, 2000).

U.S. EPA (2006) does not provide a national ambient water quality criterion for freshwater aquatic life for boron, beyond referring back to the 1986 criterion which was based on irrigation of sensitive crops. Some individual states in the U.S. have set boron guidelines for freshwater aquatic life. Missouri has an effluent limit of 2 mg/L for subsurface waters (aquifer) for aquatic life protection (U.S. EPA, 1988). Missouri does not have a criterion for the protection of aquatic life; existing criteria only address irrigation and groundwater protection (Missouri CSR, 2005). New York State has set a chronic water quality standard for the protection of freshwater aquatic life of 10 mg/L (NYCRR, 1999). Region IV of the U.S. EPA has developed a chronic surface water screening benchmark of 0.75 mg/L (U.S. EPA Region IV, 2001). In addition, Region VI of the U.S. EPA recommended a freshwater surface water benchmark screening value of 0.0016 mg/L (TNRCC, 2001). Indiana Department of Environmental Management has developed both acute and chronic water screening benchmarks of 3.2 and 0.36 mg/L, respectively (USEPA GLI

Clearinghouse, 2007). Ohio EPA has also developed both acute and chronic water screening benchmarks of 8.5 and 0.95 mg/L, respectively (USEPA GLI Clearinghouse, 2007).

CCME (1999) recommended a boron concentration of 5.0 mg/L for livestock drinking water. A boron concentration between 0.5 to 6 mg/L is recommended for agricultural irrigation water (CCME, 1999).

The Quebec Ministry of the Environment (Quebec Ministère du Développement durable, de l'Environnement et des Parcs) has boron freshwater guidelines for the protection of aquatic life that have been adopted from the Michigan Department of Environmental Quality. The Final Acute Value is 55 mg/L, the Acute Guideline (Final Acute Value divided by 2) is 28 mg/L, and the Chronic Guideline is 5 mg/L (MDDEP, 2008, pers. com.).

The maximum acceptable concentration of boron in Canadian drinking water was set to 5 mg/L (Health Canada, 1990). This interim maximum acceptable concentration was set as the availability of practicable treatment technology is inadequate to reduce boron concentrations in Canadian drinking water supplies to less than 5.0 mg/L in areas with high natural boron levels.

The British Columbia Water Protection Section of the Ministry of Water, Land and Air Protection has recommended that the boron concentration in freshwater not exceed 1.2 mg B/L for the protection of aquatic life (Moss and Nagpal, 2003). This guideline was derived based on a lowest effect level for growth inhibition on the green algae (*Selenastrum capricornutum*) of 12.3 mg/L (MELP, 1997). This lowest effect concentration was from a study which was chronic in duration and produced primary data. A safety factor of 0.1 was applied to derive the interim guideline (Moss and Nagpal, 2003).

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APPENDIX A

AQUATIC TOXICITY TABLE FOR BORON

Aquatic Toxicity Table for Boron

COMMON NAME	SPECIES NAME	LIFE STAGE	RESPONSE	TEST CONDITIONS					EFFECT CONC (mg/L)	DATA CODES KEY(1)
				pH	TEMP (°C)	DO (mg/L)	ALK. (mg/L)	HARD (mg/L)		
VERTEBRATES – Acute										
Largemouth bass	*Micropterus salmoides*	embryo-hatching stages	Teratogenesis at Hatching (3 d, NOEC)	7.5	20	8.4		204	0.109	A,F,M
Largemouth bass	*Micropterus salmoides*	embryo-hatching stages	Teratogenesis at Hatching (3 d, LOEC)	7.5	20	8.4		204	1.39	A,F,M
Largemouth bass	*Micropterus salmoides*	embryo-hatching stages)	Mortality at Hatching (3 d, NOEC)	7.5	20	8.4		204	1.39	A,F,M
Largemouth bass	*Micropterus salmoides*	embryo-hatching stages	Mortality at Hatching (3 d, LOEC)	7.5	20	8.4		204	12.17	A,F,M
Bluegill sunfish	*Lepomis macrochirus*	average size 7 cm, 5 g	Mortality (24 hr, TLm)	6.9-7.5	20		33-81	84-163	4.6	A,S
Bluegill sunfish	*Lepomis macrochirus*	average size 7 cm, 5 g	Mortality (24 hr, TLm)		20		1,750		2,389	A,S
Fathead Minnow	*Pimephales promelas*	Larval	96-h LC50	7.5-7.9	18-22	5-8.4	85-90	120	64.3	A,S,M
Fathead Minnow	*Pimephales promelas*	larval	48-h LC50	7.5-7.9	18-22	5-8.4	85-90	120	348	A,S,M
Zebrafish	*Danio rerio*	(zygotes) fertilization to free feeding	Embryonic Mortality (96 hr, LOEC, 88% mortality)						99.5 (9.2 mmol/L)[a]	A,S,M
Bonytail	*Gila elegans*	1.1 g juvenile	Mortality (96 hr, LC50)	7.0-8.5	24-26	>40% saturation	105-109	191-201	>100	A,S,U
Bonytail	*Gila elegans*	swim-up fry	Mortality (96 hr, LC50)	7.0-8.5	24-26	>40% saturation	105-109	191-201	280	A,S,U
Bonytail	*Gila elegans*	2.6 g juvenile	Mortality (96 hr, LC50)	7.0-8.5	24-26	>40% saturation	105-109	191-201	552	A,S,U
Colorado squawfish	*Ptychocheilus lucius*	0.4-1.1g juvenile	Mortality (96 hr, LC50)	7.0-8.5	24-26	>40% saturation	105-109	191-201	>100	A,S,U
Colorado squawfish	*Ptychocheilus lucius*	swim-up fry	Mortality (96 hr, LC50)	7.0-8.5	24-26	>40% saturation	105-109	191-201	279	A,S,U
Colorado squawfish	*Ptychocheilus lucius*	1.7 g juvenile	Mortality (96 hr, LC50)	7.0-8.5	24-26	>40% saturation	105-109	191-201	527	A,S,U
Razorback sucker	*Xyrauchen texanus*	2.0 g juvenile	Mortality (96 hr, LC50)	7.0-8.5	24-26	>40% saturation	105-109	191-201	>100	A,S,U
Razorback sucker	*Xyrauchen texanus*	swim-up fry	Mortality (96 hr, LC50)	7.0-8.5	24-26	>40% saturation	105-109	191-201	233	A,S,U
Razorback sucker	*Xyrauchen texanus*	0.9 g juvenile	Mortality (96 hr, LC50)	7.0-8.5	24-26	>40% saturation	105-109	191-201	279	A,S,U
Mosquito fish	*Gambusia afinis*	adult females	Mortality (96 hr, NOEC)	8.6-9.1	22-26				<204	A,S
Mosquito fish	*Gambusia afinis*	adult females	Mortality (144 hr, TLm)	8.6-9.1	22-26				215	A,S
Mosquito fish	*Gambusia afinis*	adult females	Mortality (96 hr, NOEC)	5.4-7.3	20-23				<314	A,S
Mosquito fish	*Gambusia afinis*	adult females	Mortality (96 hr, TLm)	8.6-9.1	22-26				408	A,S
Mosquito fish	*Gambusia afinis*	adult females	Mortality (48 hr, TLm)	8.6-9.1	22-26				929	A,S
Mosquito	*Gambusia afinis*	adult	Mortality	5.4-	20-23				979	A

Aquatic Toxicity Table for Boron

COMMON NAME	SPECIES NAME	LIFE STAGE	RESPONSE	TEST CONDITIONS					EFFECT CONC (mg/L)	DATA CODES KEY(1)	I QU K
				pH	TEMP (°C)	DO (mg/L)	ALK. (mg/L)	HARD (mg/L)			
fish		females	(96 hr, TLm)	7.3							
Mosquito fish	*Gambusia afinis*	adult females	Mortality (24 hr, TLm)	8.6-9.1	22-26				1,360	A,S	
Mosquito fish	*Gambusia afinis*	adult females	Mortality (48 hr, TLm)	5.4-7.3	20-23				1,834	A,S	
Mosquito fish	*Gambusia afinis*	adult females	Mortality (24 hr, TLm)	5.4-7.3	20-23				3,145	A,S	
Rainbow trout	*Oncorhyncus mykiss*	early life stages	Mortality (96hr, LC50)	7.5-7.9	14-16	5-8.4	85-90	120	275	A,S,M	
Rainbow trout	*Oncorhyncus mykiss*	early life stages	Mortality (96hr, LC50)		14-16			250	336*	A	
Rainbow trout	*Oncorhyncus mykiss; Salmo gairdneri*	adults	Mortality (48 hr, LC50)						339	A	
Rainbow trout	*Oncorhyncus mykiss*	adults	(0.5 hr, NOEC)						350	A	
Rainbow trout	*Oncorhyncus mykiss*	early life stages	Mortality (96hr, LC50)		14-16			100	379.6	A	
Rainbow trout	*Oncorhyncus mykiss*	early life stages	Mortality (96hr, LC50)		14-16			25	436.2	A	
Rainbow trout	*Oncorhyncus mykiss*	early life stages	(7 d, EC50-embryo test)						969	A,R,	
Rainbow trout	*Oncorhyncus mykiss*	adults	Obvious distress (0.5 hr)						3,500	A	
Coho salmon	*Oncorhynchus kisutch*	salmonids	Mortality (96 hr, LC50)		14-16			100	304.1	A	
Coho salmon	*Oncorhynchus kisutch*	salmonids	Mortality (96 hr, LC50)		14-16			25	357.4	A	
Coho salmon	*Oncorhynchus kisutch*	swim-up fry, 0.5 g mean weight	Mortality (96 hr, LC50)	7.47-8.17	12			210-212	447	A,S,U	
Coho salmon	*Oncorhynchus kisutch*	salmonids	Mortality (96 hr, LC50)		14-16			250	477.1	A	
Coho salmon	*Oncorhynchus kisutch*	swim-up fry, 0.5 g mean weight	Mortality (24 hr, LC50)	7.47-8.17	12			210-212	>1,000	A,S,U	
Minnow			Mortality (minimum lethal dose)		19				340-374	A	
Minnow			Mortality (minimum lethal dose)		17			hard	793-850	A	
Minnow		between 5-8 cm	Mortality (6 hr, minimum lethal dose or LOEC)		20	6.42	12.5	Distilled	3,145-3,319	A	
Minnow		between 5-8 cm	Mortality (6 hr, minimum lethal dose or LOEC)		20	6.42	150	hard	3,319-3,407	A	
Chinook	*Oncorhynchus*	0.31 g	Mortality (96hr,	7.51-	12			41.4-	566	A,S,U	

Aquatic Toxicity Table for Boron

COMMON NAME	SPECIES NAME	LIFE STAGE	RESPONSE	TEST CONDITIONS					EFFECT CONC (mg/L)	DATA CODES KEY(1)	I QU K
				pH	TEMP (°C)	DO (mg/L)	ALK. (mg/L)	HARD (mg/L)			
salmon	*tshawytscha*		LC50)	7.63				42.0			
Chinook salmon	*Oncorhynchus tshawytscha*	swim-up fry, mean weight 1.1g	Mortality (96hr, LC50)	7.47-8.17	12			210-212	725	A,S,U	
Chinook salmon	*Oncorhynchus tshawytscha*	swim-up fry, mean weight 1.1g	Mortality (24 hr, LC50)	7.47-8.17	12			210-212	>1,000	A,S,U	
Chinook salmon	*Oncorhynchus tshawytscha*	eyed egg	Mortality (24 hr, LC50)	7.51-7.63	12			41.4-42.0	>1,000	A,S,U	
Chinook salmon	*Oncorhynchus tshawytscha*	eyed egg	Mortality (96hr, LC50)	7.51-7.63	12			41.4-42.0	>1,000	A,S,U	
Chinook salmon	*Oncorhynchus tshawytscha*	alevin	Mortality (24 hr, LC50)	7.51-7.63	12			41.4-42.0	>1,000	A,S,U	
Chinook salmon	*Oncorhynchus tshawytscha*	alevin	Mortality (96hr, LC50)	7.51-7.63	12			41.4-42.0	>1,000	A,S,U	
Chinook salmon	*Oncorhynchus tshawytscha*	0.31 g	Mortality (24 hr, LC50)	7.51-7.63	12			41.4-42.0	>1,000	A,S,U	
Frog	*Xenopus laevis*	embryo-larval	Abnormal Development (4 d, NOEC)	8	22-24				35.9	A,R,M	
Frog	*Xenopus laevis*	embryo-larval	Abnormal Development (4 d, LOEC)	8	22-24				53.85	A,R,M	
Toad	*Bufo vulgaris*	embryo, from 2 cell stage to tailbud stage	Malformation (24 hr, edema, microcephalia, short tail and suppressed forebrain development)						874	A	
Toad	*Bufo vulgaris formosus*	embryo	Teratogenic Defects and Reduced Survival (24 hr)						1,747 (1% solution)	A,S	
<u>INVERTEBRATES – Acute</u>											
Flatworm	*Dugesia dorotocephala*	18-20 mm	Behaviour (1 hr, restlessness, hyperkinesia, spiralling and head/nose twist within 5 min. exposure)	6.0-8.0				370	1	A,S,U	
Flatworm	*Dugesia dorotocephala*	18-20 mm	Behaviour (1 hr, restlessness, hyperkinesia, spiralling and head/nose twist within 5 min. exposure)	6.0-8.0				370	10	A,S,U	
Protozoan	*Entosiphon sulcatum*		Cell Replication (72 hr, TT, 5% reduction in cell replication)	6.9	25				1	A,S	(a re in
Amphipod	*Hyalella azteca*	1-11 d	Mortality (48h, LC50)	7.5-7.9	22	5-8.4	85-90	120	140	A,S,M	

Aquatic Toxicity Table for Boron

COMMON NAME	SPECIES NAME	LIFE STAGE	RESPONSE	TEST CONDITIONS					EFFECT CONC (mg/L)	DATA CODES KEY(1)
				pH	TEMP (°C)	DO (mg/L)	ALK. (mg/L)	HARD (mg/L)		
Amphipod	*Hyalella azteca*		Mortality (96 hr, LC50)		22-24			25	28.9	A
Amphipod	*Hyalella azteca*		Mortality (96 hr, LC50)		22-24			100	291.3	A
Amphipod	*Hyalella azteca*		Mortality (96 hr, LC50)		22-24			250	333.6	A
Water Flea	*Daphnia magna*	neonates	Mortality (48 hr, LC50)		19-21			25	21.3	A
Water Flea	*Daphnia magna*	< 24 hr old	(NOEC)					100	25.6	A,S
Water Flea	*Daphnia magna*	< 24 hr old	Mortality (LOEC)					100	50	A,S
Water Flea	*Daphnia magna*	< 24 hr old	(NOEC)					250	50	A,S
Water Flea	*Daphnia magna*	neonates	Mortality (48 hr, LC50)		19-21			100	52.4	A
Water Flea	*Daphnia magna*	< 24 hr old	Mortality (LOEC)					250	100	A,S
Water Flea	*Daphnia magna* straus	< 24 hr old	Mortality (48 hr, LC50)	6.7-8.1	20.1-20.7	5.39 (> 60% saturation)	53-63	141-155	133 (115-153)	A,S,U
Water Flea	*Daphnia magna*	neonates	Mortality (48 hr, LC50)		19-21			250	139.2	A
Water Flea	*Daphnia magna*	neonate	Mortality (48 hr, LC50)	9.0-9.2	19.9-20.1	8.4-8.8		10.6-170	141	A,R,M
Water Flea	*Daphnia magna*	<24 h old	Mortality (48-h LC50)	7.5-7.9	18-22	5-8.4	85-90	120	165	A,S,M
Water Flea	*Daphnia magna* straus	<24 hr old	Mortality (48 hr, NOEC)	7.1-8.7	18-21	>9		135-217	<200	A,S,M
Water Flea	*Daphnia magna* straus	<24 hr old	Mortality (48 hr, LC50)	7.1-8.7	18-21	>9		135-217	226	A,S,M
Mosquito larvae	*Anopheles quadrimaculatus*		Mortality (48 hr, 92% mortality)						25	A
Mosquito larvae	3 species	through hatching	Mortality (LC97-LC99, through hatching)						43.7	A
Mosquito larvae	*Anopheles quadrimaculatus*		Mortality (25hr, 100% mortality)						125	A
Mosquito larvae	3 species	second instar	Mortality (48 hr, LC100)						524	A
Mosquito larvae	3 species	freshly hatched	Mortality (48 hr, LC100)						700	A
Mosquito larvae	3 species	third instar	Mortality (48 hr, LC100)						1,748	A
Mosquito larvae	3 species	pupae	Mortality (48 hr, LC100)						2,797	A
Midge	*Chironomus tentans*	third instar larval	Mortality (96 hr, LC50)		22-24			100	118	A
Midge	*Chironomus tentans*	third instar larval	Mortality (96 hr, LC50)		22-24			250	137.7	A
Midge	*Chironomus*	third instar	Mortality		22-24			25	157.3	A

Aquatic Toxicity Table for Boron

COMMON NAME	SPECIES NAME	LIFE STAGE	RESPONSE	TEST CONDITIONS					EFFECT CONC (mg/L)	DATA CODES KEY(1)	I QU K
				pH	TEMP (°C)	DO (mg/L)	ALK. (mg/L)	HARD (mg/L)			
	tentans	larval	(96 hr, LC50)								
Midge	*Chironomus tentans*	third instar larval	Mortality (48 hr, LC50)	7.5-7.9	22	5-8.4	85-90	120	242	A,S,M	
Midge	*Chironomus decorus*	larvae, fourth instar	Mortality (48 hr, LC50)	9.0-9.2	19.9-20.1	8.4-8.8		10.6-170	1,376	A,R,M	
<u>VERTEBRATES – Chronic</u>											
Rainbow trout	*Oncorhyncus mykiss; Salmo gairdneri*	embryo larval stages	(28 d, NOEC)	7.9	13.3	9.6	82	200	0.001	C,F,	
Rainbow trout	*Oncorhyncus mykiss; Salmo gairdneri*	embryo larval stages	Mortality (28 d, LC1)	7.9	13.3	9.6	82	200	0.001	C,F,	
Rainbow trout	*Oncorhyncus mykiss; Salmo gairdneri*	embryo larval stages	(28 d, LOEC)	7.9	13.3	9.6	82	200	0.01^{b}	C,F,	
Rainbow trout	*Oncorhyncus mykiss; Salmo gairdneri*	freshly fertilized eggs	(32 d, NOEC)					200	0.01	C,F,	(Pr info
Rainbow trout	*Oncorhyncus mykiss*		Mortality (NOEC)						0.04	C	
Rainbow trout	*Oncorhyncus mykiss; Salmo gairdneri*	embryo larval stages	Mortality (28 d, LC1)	7.9	14	10.1		50	0.07	C,F,	
Rainbow trout	*Oncorhyncus mykiss; Salmo gairdneri*	embryo larval stages	Mortality (28 d, LC1)	7.8	13	10.3	82	200	0.07	C,F,	
Rainbow trout	*Oncorhyncus mykiss*		Mortality (32 d, LOEC)						~0.1	C	
Rainbow trout	*Oncorhyncus mykiss; Salmo gairdneri*	freshly fertilized eggs	(32 d, LOEC)					200	0.1^{b}	C,F,	Pr inf
Rainbow trout	*Oncorhyncus mykiss; Salmo gairdneri*	embryo larval stages	Mortality (28 d, LC1)	7.7	13.7	9.2		50	0.1	C,F,	
Rainbow trout	*Oncorhyncus mykiss*	embryo-larval stages	Mortality at Hatching (32 d, LOEC)	7.4	13.2	9.8		197	0.1^{b}	C,F,M	
Rainbow trout	*Oncorhyncus mykiss*	embryo-larval stages	Teratogenesis at Hatching (32 d, LOEC)	7.4	13.2	9.8		197	0.1^{b}	C,F,M	
Rainbow trout	*Oncorhyncus mykiss*	embryo-larval stages	Mortality at 8-d Post-hatch (36 d, NOEC)	7.5-7.9	13.4-14	9.7-10.3	47-61	178-198	0.103	C,F,M	
Rainbow trout	*Oncorhyncus mykiss*	embryo-larval stages	Teratogenesis at 8-d Post-hatch (36 d, NOEC)	7.5-7.9	13.4-14	9.7-10.3	47-61	178-198	0.103	C,F,M	
Rainbow trout	*Oncorhyncus mykiss*	embryo-hatching stages	Mortality at Hatching (28 d, NOEC)	7.5-7.9	13.4-14	9.7-10.3	47-61	178-198	0.103	C,F,M	
Rainbow trout	*Oncorhyncus mykiss; Salmo gairdneri*	embryo-larval stages	(28 d, NOEC)	7.7	13.7	9.2		50	0.11	C,F,	
Rainbow trout	*Oncorhyncus mykiss;*	early life stages	(36 d, NOEC)						0.75	C,F,	(Pr

Aquatic Toxicity Table for Boron

COMMON NAME	SPECIES NAME	LIFE STAGE	RESPONSE	TEST CONDITIONS					EFFECT CONC (mg/L)	DATA CODES KEY(1)	QU K
				pH	TEMP (°C)	DO (mg/L)	ALK. (mg/L)	HARD (mg/L)			
	Salmo gairdneri										info
Rainbow trout	*Oncorhyncus mykiss; Salmo gairdneri*	embryo-larval stages	(28 d, NOEC)	7.9	14	10.1		50	0.96	C,F,	
Rainbow trout	*Oncorhyncus mykiss; Salmo gairdneri*	embryo-larval stages	(28 d, LOEC)	7.7	13.7	9.2		50	1[b]	C,F,	
Rainbow trout	*Oncorhyncus mykiss; Salmo gairdneri*	early life stages	(36 d, LOEC)						1	C,F,	(Pr info
Rainbow Trout	*Oncorhyncus mykiss*	embryo-larval stages	Mortality at 8-d Post-hatch (36 d, LOEC)	7.5-7.9	13.4-14	9.7-10.3	47-61	178-198	1.34	C,F,M	
Rainbow Trout	*Oncorhyncus mykiss*	embryo-larval stages	Teratogenesis at 8-d Post-hatch (36 d, LOEC)	7.5-7.9	13.4-14	9.7-10.3	47-61	178-198	1.34	C,F,M	
Rainbow Trout	*Oncorhyncus mykiss*	embryo-hatching stages	Mortality at Hatching (28 d, LOEC)	7.5-7.9	13.4-14	9.7-10.3	47-61	178-198	1.34	C,F,M	
Rainbow Trout	*Oncorhyncus mykiss*	embryo-hatching stages	Teratogenesis at Hatching (28 d, NOEC)	7.5-7.9	13.4-14	9.7-10.3	47-61	178-198	1.34	C,F,M	
Rainbow Trout	*Oncorhyncus mykiss*	embryo-larval stages	Mortality (larval survival) at 60-d Post-hatch (87 d, NOEC)	6.8-7.1	11-13		25-38	24-39	2.1	C,F,M	
Rainbow Trout	*Oncorhyncus mykiss*	embryo-larval stages	Larval Growth at 60-d Post-hatch (87 d, NOEC)	6.8-7.1	11-13		25-38	24-39	2.1	C,F,M	
Rainbow Trout	*Oncorhyncus mykiss*	embryo-larval stages	Embryo Survival at 60-d Post-hatch (87 d, NOEC)	6.8-7.1	11-13		25-38	24-39	2.1	C,F,M	
Rainbow Trout	*Oncorhyncus mykiss*	embryo-larval stages	Embryo Viability at 60-d Post-hatch (87 d, NOEC)	6.8-7.1	11-13		25-38	24-39	2.1	C,F,M	
Rainbow trout	*Oncorhyncus mykiss; Salmo gairdneri*	embryo larval stages	(28 d, NOEC)	7.8	13	10.3	82	200	9.63	C,F,	
Rainbow trout	*Oncorhyncus mykiss; Salmo gairdneri*	embryo larval stages	(28 d, LOEC)	7.9	14	10.1		50	9.7	C,F,	
Rainbow Trout	*Oncorhyncus mykiss*	embryo-hatching stages	Teratogenesis at Hatching (28 d, LOEC)	7.5-7.9	13.4-14	9.7-10.3	47-61	178-198	11.46	C,F,M	
Rainbow trout	*Oncorhyncus mykiss; Salmo gairdneri*	early life stages	(60 d, LOEC)	6.5-7.5				27	>17	C,F,	(Pr info
Rainbow trout	*Oncorhyncus mykiss*	20 d embryo-larval stages	Larval Growth at 60-d Post-hatch (67 d, NOEC)	6.8-7.1	11-13		25-38	24-39	18	C,F,M	

Aquatic Toxicity Table for Boron

COMMON NAME	SPECIES NAME	LIFE STAGE	RESPONSE	TEST CONDITIONS					EFFECT CONC (mg/L)	DATA CODES KEY(1)	I QU K
				pH	TEMP (°C)	DO (mg/L)	ALK. (mg/L)	HARD (mg/L)			
Rainbow trout	*Oncorhyncus mykiss*	20 d embryo-larval stages	Embryo Survival at 60-d Post-hatch (67 d, NOEC)	6.8-7.1	11-13		25-38	24-39	18	C,F,M	
Rainbow trout	*Oncorhyncus mykiss*	20 d embryo-larval stages	Larval Survival at 60-d Post-hatch (67 d, NOEC)	6.8-7.1	11-13		25-38	24-39	18	C,F,M	
Rainbow trout	*Oncorhyncus mykiss; Salmo gairdneri*	embryo larval stages	Mortality (28 d, LC50)	7.9	14	10.1		50	27	C,F,	
Rainbow trout	*Oncorhyncus mykiss; Salmo gairdneri*	embryo larval stages	(28 d, LOEC)	7.8	13	10.3	82	200	49.7	C,F,	
Rainbow trout	*Oncorhyncus mykiss; Salmo gairdneri*	embryo larval stages	Mortality (28 d, LC50)	7.8	13	10.3	82	200	54	C,F,	
Rainbow trout	*Oncorhyncus mykiss; Salmo gairdneri*	embryo larval stages	Mortality (28 d, LC50)	7.9	13.3	9.6	82	200	79	C,F,	
Rainbow trout	*Oncorhyncus mykiss; Salmo gairdneri*	embryo larval stages	Mortality (28 d, LC50)	7.7	13.7	9.2		50	100	C,F,	
Rainbow trout	*Oncorhynchus mykiss*	embryo (fertilization to 2 weeks post-hatch)	Embryonic Mortality (6 wk, LOEC, 85 to 95% mortality)		12.5				108 (10 mmol B/L)[a]	C,M	
Rainbow trout	*Oncorhyncus mykiss*	embryo larval stages	Mortality (32 d, LC50)	7.4	13.2	9.8		197	138	C,F,M	
Rainbow trout	*Oncorhyncus mykiss*		Mortality (32 d, LC50)						~138	C	
Rainbow trout	*Oncorhyncus mykiss; Salmo gairdneri*		Darkening of skin, immobilization and loss of equilibrium						874	C	(C pu in
Goldfish	*Carassius auratus*	embryo larval stages	Mortality (7 d, LC1)	7.6	24.8	7.5	82	200	0.2	C,F,	
Goldfish	*Carassius auratus*	embryo larval stages	Mortality (7 d, LC1)	7.9	24.8	7.4		50	0.6	C,F,	
Goldfish	*Carassius auratus*	embryo larval stages	Mortality (7 d, LC1)	8.1	27	7.5	82	200	0.9	C,F,	
Goldfish	*Carassius auratus*	embryo larval stages	Mortality (7 d, LC1)	8.3	27	7.5		50	1.4	C,F,	
Goldfish	*Carassius auratus*	embryo larval stages	Mortality (7 d, LC50)	8.3	27	7.5		50	6.5	C,F,	
Goldfish	*Carassius auratus*	embryo larval stages	(7 d, NOEC)	7.6	24.8	7.5	82	200	6.8	C,F,	
Goldfish	*Carassius auratus*	embryo larval stages	(7 d, LOEC)	7.6	24.8	7.5	82	200	8.33	C,F,	
Goldfish	*Carassius auratus*	embryo larval stages	(7 d, NOEC)	8.1	27	7.5	82	200	8.53	C,F,	
Goldfish	*Carassius*	embryo	(7 d, NOEC)	7.9	24.8	7.4		50	9.2	C,F,	

Aquatic Toxicity Table for Boron

COMMON NAME	SPECIES NAME	LIFE STAGE	RESPONSE	TEST CONDITIONS					EFFECT CONC (mg/L)	DATA CODES KEY(1)	QU K
				pH	TEMP (°C)	DO (mg/L)	ALK. (mg/L)	HARD (mg/L)			
	auratus	larval stages									
Goldfish	*Carassius auratus*	embryo larval stages	(7 d, LOEC)	7.9	24.8	7.4		50	22.5	C,F,	
Goldfish	*Carassius auratus*	embryo larval stages	(7 d, NOEC)	8.3	27	7.5		50	26.5	C,F,	
Goldfish	*Carassius auratus*	embryo larval stages	(7 d, LOEC)	8.1	27	7.5	82	200	27.33	C,F,	
Goldfish	*Carassius auratus*	embryo larval stages	Mortality (7 d, LC50)	7.9	24.8	7.4		50	46	C,F,	
Goldfish	*Carassius auratus*	embryo larval stages	(7 d, LOEC)	8.3	27	7.5		50	48.75	C,F,	
Goldfish	*Carassius auratus*	embryo larval stages	Mortality (7 d, LC50)	8.1	27	7.5	82	200	59	C,F,	
Goldfish	*Carassius auratus*	embryo larval stages	Mortality (7 d, LC50)	7.6	24.8	7.5	82	200	75	C,F,	
Channel catfish	*Ictalurus punctatus*	embryo larval stages	Mortality (9 d, LC1)	7.6	24.7	7.6	82	200	0.2	C,F,	
Channel catfish	*Ictalurus punctatus*	embryo larval stages	(9 d, NOEC)	8.2	29.4	6.5	82	200	0.49	C,F,	
Channel catfish	*Ictalurus punctatus*	embryo larval stages	Mortality (9 d, LC1)	7.5	25	7.3		50	0.5	C,F,	
Channel catfish	*Ictalurus punctatus*	embryo larval stages	(9 d, NOEC)	7.6	24.7	7.6	82	200	0.75	C,F,	
Channel catfish	*Ictalurus punctatus*	embryo larval stages	(9 d, LOEC)	7.6	24.7	7.6	82	200	1	C,F,	
Channel catfish	*Ictalurus punctatus*	embryo larval stages	(9 d, NOEC)	7.5	25	7.3		50	1.01	C,F,	
Channel catfish	*Ictalurus punctatus*	embryo larval stages	(9 d, LOEC)	8.2	29.4	6.5	82	200	1.04	C,F,	
Channel catfish	*Ictalurus punctatus*	embryo larval stages	Mortality (9 d, LC1)	8.2	29.4	6.5	82	200	1.7	C,F,	
Channel catfish	*Ictalurus punctatus*	embryo larval stages	(9 d, LOEC)	7.5	25	7.3		50	5.42	C,F,	
Channel catfish	*Ictalurus punctatus*	embryo larval stages	Mortality (9 d, LC1)	8.5	29.4	6.4		50	5.5	C,F,	
Channel catfish	*Ictalurus punctatus*	embryo larval stages	(9 d, NOEC)	8.5	29.4	6.4		50	9	C,F,	
Channel catfish	*Ictalurus punctatus*	embryo larval stages	Mortality (9 d, LC50)	7.6	24.7	7.6	82	200	22	C,F,	
Channel catfish	*Ictalurus punctatus*	embryo larval stages	(9 d, LOEC)	8.5	29.4	6.4		50	25.9	C,F,	

Aquatic Toxicity Table for Boron

COMMON NAME	SPECIES NAME	LIFE STAGE	RESPONSE	TEST CONDITIONS					EFFECT CONC	DATA CODES	I
				pH	TEMP (°C)	DO (mg/L)	ALK. (mg/L)	HARD (mg/L)	(mg/L)	KEY(1)	QU K
Channel catfish	*Ictalurus punctatus*	embryo larval stages	Mortality (9 d, LC50)	8.2	29.4	6.5	82	200	71	C,F,	
Channel catfish	*Ictalurus punctatus*	embryo larval stages	Mortality (9 d, LC50)	7.5	25	7.3		50	155	C,F,	
Channel catfish	*Ictalurus punctatus*	embryo larval stages	Mortality (9 d, LC50)	8.5	29.4	6.4		50	155	C,F,	
Largemouth bass	*Micropterus salmoides*	embryo-larval stages	Mortality at 8-d Post-hatch (11 d, NOEC)	7.5	20	8.4		204	1.39	C,F,M	
Largemouth bass	*Micropterus salmoides*	freshly fertilized eggs	(11 d, NOEC)					200	1.39	C,F,	(Pr info
Largemouth bass	*Micropterus salmoides*	embryo-larval stages	Mortality at 8-d Post-hatch (11 d, LOEC)	7.5	20	8.4		204	12.17	C,F,M	
Largemouth bass	*Micropterus salmoides*	freshly fertilized eggs	(11 d, LOEC)					200	12.17	C,F,	(Pr info
Largemouth bass	*Micropterus salmoides*	embryo-larval stages	Mortality (11 d, LC50)	7.5	20	8.4		204	92	C,F,M	
Leopard Frog	*Rana pipiens*	embryo-larval stages	Mortality (7.5 d, LC1)	8.4	25.3	7.8	82	200	3	C,F,	
Leopard Frog	*Rana pipiens*	embryo-larval stages	Mortality (7.5 d, LC1)	8.3	25.3	7.7		50	5	C,F,	
Leopard Frog	*Rana pipiens*	embryo-larval stages	(7 d NOEC)	8.4	25.3	7.8	82	200	7.04	C,F,	
Leopard Frog	*Rana pipiens*	embryo-larval stages	(7 d NOEC)	8.3	25.3	7.7		50	7.04	C,F,	
Leopard Frog	*Rana pipiens*	embryo-larval stages	(7 d, LOEC)	8.3	25.3	7.7		50	9.6	C,F,	
Leopard Frog	*Rana pipiens*	embryo-larval stages	(7 d, LOEC)	8.4	25.3	7.8	82	200	10.5	C,F,	
Leopard Frog	*Rana pipiens*	embryo-larval stages	Mortality (7.5 d, LC1)	7.7	25	7.7		50	13	C,F,	
Leopard Frog	*Rana pipiens*	embryo-larval stages	Mortality (7.5 d, LC1)	7.7	25	7.8	82	200	22	C,F,	
Leopard Frog	*Rana pipiens*	embryo-larval stages	(7 d NOEC)	7.7	25	7.7		50	32.5	C,F,	
Leopard Frog	*Rana pipiens*	embryo-larval stages	(7 d NOEC)	7.7	25	7.8	82	200	45.7	C,F,	
Leopard Frog	*Rana pipiens*	embryo-larval stages	Mortality (7.5 d, LC50)	8.3	25.3	7.7		50	47	C,F,	
Leopard Frog	*Rana pipiens*	embryo-larval stages	(7 d, LOEC)	7.7	25	7.7		50	47.5	C,F,	
Leopard	*Rana pipiens*	embryo-	Mortality	8.4	25.3	7.8	82	200	54	C,F,	

Aquatic Toxicity Table for Boron

COMMON NAME	SPECIES NAME	LIFE STAGE	RESPONSE	TEST CONDITIONS					EFFECT CONC (mg/L)	DATA CODES KEY(1)
				pH	TEMP (°C)	DO (mg/L)	ALK. (mg/L)	HARD (mg/L)		
Frog		larval stages	(7.5 d, LC50)							
Leopard Frog	*Rana pipiens*	embryo-larval stages	(7 d, LOEC)	7.7	25	7.8	82	200	86	C,F,
Leopard Frog	*Rana pipiens*	embryo-larval stages	Mortality (7.5 d, LC50)	7.7	25	7.7		50	130	C,F,
Leopard Frog	*Rana pipiens*	embryo-larval stages	Mortality (7.5 d, LC50)	7.7	25	7.8	82	200	135	C,F,
Zebrafish	*Brachydanio rerio*		mortality, growth, condition (34-d MATC)						10.04	
Fathead minnow	*Pimeohales promelas*	eggs and fry	Growth Reduction (30 d, NOEC)	7.1-7.9	25		33-38	38-46	14	C,F,
Fathead minnow	*Pimephales promelas*	Larval	Growth Inhibition (7d IC25)	7.5-7.9	18-22	5-8.4	85-90	120	20.6 (8.5-26.5)	C,R,M
Fathead minnow	*Pimephales promelas*	eggs and fry	Growth Reduction (30 d, LOEC)	7.1-7.9	25		33-38	38-46	24	C,F,
Fathead minnow	*Pimephales promelas*	eggs and fry	Reduced Fry Survival (60 d, NOEC)	7.1-7.9	25		33-38	38-46	24	C,F,
Fathead minnow	*Pimeohales promelas*	eggs and fry	Reduced Fry Survival (60 d, LOEC)	7.1-7.9	25		33-38	38-46	88	C,F,
Fowler's toad	*Bufo fowleri*	embryo-larval stages	Mortality (7 d, LC1)	7.6	23.7	6.8	85	200	5	C,F,
Fowler's toad	*Bufo fowleri*	embryo-larval stages	(7 d, NOEC)	7.6	23.7	6.8	82	200	22.3	C,F,
Fowler's toad	*Bufo fowleri*	embryo-larval stages	Mortality (7.5 d, LC1)	7.6	23.7	6.8		50	25	C,F,
Fowler's toad	*Bufo fowleri*	embryo-larval stages	(7 d, NOEC)	7.6	23.7	6.8		50	48.7	C,F,
Fowler's toad	*Bufo fowleri*	embryo-larval stages	(7 d, LOEC)	7.6	23.7	6.8	82	200	53.5	C,F,
Fowler's toad	*Bufo fowleri*	embryo-larval stages	(7 d, LOEC)	7.6	23.7	6.8		50	96	C,F,
Fowler's toad	*Bufo fowleri*	embryo-larval stages	Mortality (7d, LC50)	7.6	23.7	6.8	82	200	123	C,F,
Fowler's toad	*Bufo fowleri*	embryo-larval stages	Mortality (7.5 d, LC50)	7.6	23.7	6.8		50	145	C,F,
Wood frog	*Rana sylvatica*	blastula	Proportion of	6.5	10				50	C,S,M

Aquatic Toxicity Table for Boron

COMMON NAME	SPECIES NAME	LIFE STAGE	RESPONSE	TEST CONDITIONS					EFFECT CONC (mg/L)	DATA CODES KEY(1)
				pH	TEMP (°C)	DO (mg/L)	ALK. (mg/L)	HARD (mg/L)		
		lifestage eggs	Deformed Hatchlings (13-23 d, LOEC, 51% increase in deformities compared to controls)							
Wood frog	*Rana sylvatica*	blastula lifestage eggs	Proportion of Eggs Hatched (13-23 d, NOEC)	6.5	10				100	C,S,M
Wood frog	*Rana sylvatica*	blastula lifestage eggs	Proportion of Deformed Hatchlings (13-23 d, 77% increase in deformities compared to controls)	6.5	10				100	C,S,M
Jefferson salamander	*Ambystoma jeffersonianum*	blastula lifestage eggs	Proportion of Deformed Hatchlings (17-25 d, LOEC, 7% increase in deformities compared to controls)	6.5	10				50	C,S,M
Jefferson salamander	*Ambystoma jeffersonianum*	blastula lifestage eggs	Proportion of Eggs Hatched (17-25 d, NOEC)	6.5	10				100	C,S,M
Jefferson salamander	*Ambystoma jeffersonianum*	blastula lifestage eggs	Proportion of Deformed Hatchlings (17-25 d, 13% increase in deformities compared to controls)	6.5	10				100	C,S,M
Spotted salamander	*Ambystoma maculatum*	blastula lifestage eggs	Proportion of Deformed Hatchlings (38-44 d, LOEC, 18% increase in deformities compared to controls)	6.5	10				50	C,S,M
Spotted salamander	*Ambystoma maculatum*	(blastula lifestage eggs	Proportion of Eggs Hatched (38-44 d, NOEC)	6.5	10				100	C,S,M
Spotted salamander	*Ambystoma maculatum*	blastula lifestage eggs	Proportion of Deformed Hatchlings (38-44 d, 80% increase in deformities compared to controls)	6.5	10				100	C,S,M
American	*Bufo*	blastula	Proportion of	6.5	10				50	C,S,M

Aquatic Toxicity Table for Boron

COMMON NAME	SPECIES NAME	LIFE STAGE	RESPONSE	TEST CONDITIONS					EFFECT CONC (mg/L)	DATA CODES KEY(1)
				pH	TEMP (°C)	DO (mg/L)	ALK. (mg/L)	HARD (mg/L)		
toad	*americanus*	lifestage eggs	Eggs Hatching (15-23 d, LOEC, 43% decrease compared to controls)							
American toad	*Bufo americanus*	blastula lifestage eggs	Proportion of Eggs Hatching (15-23 d, 71% decrease compared to controls)	6.5	10				100	C,S,M
Coho salmon	*Onchorhynchus kisutch*	alevins and fry	Mortality (23 d, LC50)	7	11				93	C,R
Coho salmon	*Onchorhynchus kisutch*	alevins 0.19-0.7 g	Mortality (283 hr, LC50)		11			47	113 (104-123 95% CLs)	C,R
<u>INVERTEBRATES – Chronic</u>										
Water Flea	*Daphnia magna*		Immobilization (threshold concentration)		25				<0.38	C
Water Flea	*Daphnia magna*		Growth (21d MATC)						4.665	C
Water Flea	*Daphnia magna*		Reproduction (NOEC)						6	C
Water Flea	*Daphnia magna* straus		Mean Brood Sizes (21 d, NOEC)	7.1-8.7	18-21	>9		135-217	6	C,R,M
Water Flea	*Daphnia magna*		(21 d, NOEC)	8.0-8.2	19.5-20.5	7.3-8.0	53-63	141-155	6.4	C,S,R,M
Water Flea	*Daphnia magna*		Growth (21 d, MATC)	8.0-8.2	19.5-20.5	7.3-8.0	53-63	141-155	~9.3	C,S,R,M
Water Flea	*Daphnia magna*	(<24 hr old)	(NOEC)					250	12.4	C,S
Water Flea	*Daphnia magna* straus		Mean Brood Sizes (21 d, LOEC)	7.1-8.7	18-21	>9		135-217	13	C,R,M
Water Flea	*Daphnia magna*	(<24 hr old)	(NOEC)					100	13.1	C,S
Water Flea	*Daphnia magna* straus		(21 d, LOEC)	8.0-8.2	19.5-20.5	7.3-8.0	53-63	141-155	13.6	C,S,R,M
Water Flea	*Daphnia magna* straus		Reproduction (LOEC, mean number of broods per daphnid, mean total number of young per daphnid, mean brood size per daphnid, and mean size)	8.0-8.2	19.5-20.5	7.3-8.0	53-63	141-155	14	C,S,R,M
Water Flea	*Daphnia magna*	(<24 hr old)	(LOEC)					100	25.4	C,S
Water Flea	*Daphnia magna*	(<24 hr old)	(LOEC)					250	26.4	C,S
Water Flea	*Daphnia magna*		Mean Length	7.1-	18-21	>9		135-	27	C,R,M

Aquatic Toxicity Table for Boron

COMMON NAME	SPECIES NAME	LIFE STAGE	RESPONSE	TEST CONDITIONS					EFFECT CONC	DATA CODES
				pH	TEMP (°C)	DO (mg/L)	ALK. (mg/L)	HARD (mg/L)	(mg/L)	KEY(1)
	straus		(21 d, NOEC)	8.7				217		
Water Flea	*Daphnia magna* straus		Mean Brood Sizes (21 d, 31% decrease compared to controls)	7.1-8.7	18-21	>9		135-217	27	C,R,M
Water Flea	*Daphnia magna*		Immobilization (threshold concentration)						<27.2	C
Water Flea	*Daphnia magna* straus		Mortality (21 d, LC50)	7.3-8.0	20			150	52.2	C,S,R,M
Water Flea	*Daphnia magna* straus		Mean Length (21 d, LOEC)	7.1-8.7	18-21	>9		135-217	53	C,R,M
Water Flea	*Daphnia magna* straus		Number of Offspring Produced (21 d, 70% decrease compared to controls)	7.1-8.7	18-21	>9		135-217	53	C,R,M
Water Flea	*Daphnia magna* straus		Mean Brood Sizes (21 d, 50% decrease compared to controls)	7.1-8.7	18-21	>9		135-217	53	C,R,M
Water Flea	*Daphnia magna* straus	adult	Mortality (21 d, LC50)	7.1-8.7	18-21	>9		135-217	53.2 (44.1-64.5)	C,R,M
Water Flea	*Daphnia magna*		Mortality (21 d, LC50)						~266	C
Water Flea	*Ceriodaphnia dubia*		Growth, reproduction (14-d MATC)						13.4	
Amphipod	*Hyalella azteca*	1-11 d	Mortality (7 d, LC50)	7.23-8.83	24-25		14	18	2.935	A,S,M
Amphipod	*Hyalella azteca*	1-11 d	Mortality (7 d, LC50)	6.44-8.52	24-25		84	124	>3.15	A,S,U
Unknown - Protozoa???	*Opercularia bimarginata*		Growth, reporduction (72-h NOEC)						10	
Protozoa	*Entosiphon sulcatum*		Growth (72-h NOEC)						15	
Protozoa	*Paramecium caudatum*		Growth, reporduction (72-h NOEC)						20	
Midge	*Chironomus decorus*	larvae, fourth instar	Growth Rate (96 hr, NOEC, inhibited growth rate)	9.0-9.2	19.9-20.1	8.4-8.8		10.6-170	<20	C,R,M
Midge	*Chironomus decorus*	larvae, fourth instar	Growth Rate (96 hr, LOEC, significantly inhibited growth rate)	9.0-9.2	19.9-20.1	8.4-8.8		10.6-170	20	C,R,M

PLANTS – Chronic

Aquatic Toxicity Table for Boron

COMMON NAME	SPECIES NAME	LIFE STAGE	RESPONSE	TEST CONDITIONS					EFFECT CONC (mg/L)	DATA CODES KEY(1)	QU K
				pH	TEMP (°C)	DO (mg/L)	ALK. (mg/L)	HARD (mg/L)			
Blue Green Algae	*Anacystis nidulans*		Growth (NOEC)						0.01-4.0	C	
Blue Green Algae	*Anacystis nidulans*		Growth or Organic Constituents (NOEC)						50	C	
Blue Green Algae	*Anacystis nidulans*		Signficantly decreased growth and chlorophyll content						75	C	
Blue Green Algae	*Anacystis nidulans*		Decreased chlorophyll content and photosynthesis inhibition within 72 hrs						100	C	
Blue Green Algae	*Anacystis nidulans*		Decreased protein content causing inhibition in nitrate uptake and nitrate reductase activity						100	C	
Green Alga	*Chlorella pyrenoidosa*		Population Growth (14 d, NOEC)						0.4	C	
Green Alga	*Chlorella pyrenoidosa*		Growth or Cell Composition (NOEC)						10	C	
Green Alga	*Chlorella pyrenoidosa*		Decreased algal growth; increase in protein and nucleic acid synthesis						≥25	C	Pu in
Green Alga	*Chlorella pyrenoidosa*		Altered cell division and amino acid activiity after 72 hr; reversible photosynthesis inhibition; giant cells formed with increased nitrate and protein						50-100	C	
Green Alga	*Chlorella pyrenoidosa*		Cell Division and Biomass Synthesis (72 hr, totally inhibitory)						>100	C	
Duckweed	*Spirodella polyrrhiza*		Frond Production (10 d, NOEC)	5.2-5.8	24-26				0.9	C,R,M	
Duckweed	*Spirodella polyrrhiza*		Frond Production (10 d, LOEC)	5.2-5.8	24-26				3.5	C,R,M	
Duckweed	*Spirodella polyrrhiza*		Growth Rate (10d, NOEC)	5.2-5.8	24-26				6.1	C,R,M	

Aquatic Toxicity Table for Boron

COMMON NAME	SPECIES NAME	LIFE STAGE	RESPONSE	TEST CONDITIONS pH	TEMP (°C)	DO (mg/L)	ALK. (mg/L)	HARD (mg/L)	EFFECT CONC (mg/L)	DATA CODES KEY(1)
Duckweed	*Spirodella polyrrhiza*		Reduced Growth Rate (10d, EC50)	5.2-5.8	24-26				11.7	C,R,M
Duckweed	*Spirodella polyrrhiza*		Reduced Frond Production (10 d, EC50)	5.2-5.8	24-26				14.3	C,R,M
Duckweed	*Spirodella polyrrhiza*		Abnormal Frond Occurrence (chlorotic, necrotic, dead) (10 d, EC50)	5.2-5.8	24-26				17.7	C,R,M
Duckweed	*Spirodella polyrrhiza*		Growth Rate (10d, LOEC)	5.2-5.8	24-26				18.9	C,R,M
Duckweed	*Spirodella polyrrhiza*		Abnormal Fronds (chlorotic, necrotic, dead) (10 d, NOEC)	5.2-5.8	24-26				18.9	C,R,M
Duckweed	*Spirodella polyrrhiza*		Abnormal Fronds (chlorotic, necrotic, dead) (10 d, LOEC)	5.2-5.8	24-26				22.4	C,R,M
American waterweed	*Elodea canadensis*		Growth inhibition						1	C
American waterweed	*Elodea canadensis*		(NOEC)						1	C
American waterweed	*Elodea canadensis*		Mortality (21 d, LC50)						~5.0	C
Stream water-crowfoot	*Ranunculus penicillatus*		Growth inhibition						1	C
Water milfoil	*Myriophyllum alterniflourum*		Growth inhibition						2	C
Common reed	*Phragmites australis*		growth (4-month, NOEC)						< 4	
Duckweed	*Lemna minor*		Decreased fresh weight per plant						5	C
Duckweed	*Lemna minor*		Growth (7-d NOEC)						60	
Duckweed	*Lemna minor*		Growth inhibition	5					100	C
Chlorella algae	*Chlorella vulgaris*		Population Growth (NOEC)						5.2	C
Green Alga	*Selenastrum capricornutum*	4-7 d old	NOEC (72 hr)		22-26				<12.3	C,S
Green Alga	*Selenastrum*	4-7 d old	LOEC (72 hr)		22-26				12.3	C,S

Aquatic Toxicity Table for Boron

COMMON NAME	SPECIES NAME	LIFE STAGE	RESPONSE	TEST CONDITIONS					EFFECT CONC (mg/L)	DATA CODES KEY(1)	QU K
				pH	TEMP (°C)	DO (mg/L)	ALK. (mg/L)	HARD (mg/L)			
	capricornutum										
Green Alga	*Scenedesmus subpicatus*		Growth (96-h EC 10)						30		
Spiked or Eurasian watermillfoil	*Myriophyllum spicatum*		(32 d, EC50)						~171	C	
Spiked or Eurasian watermillfoil	*Myriophyllum spicatum*		(NOEC)						34.2	C	
Spiked or Eurasian watermillfoil	*Myriophyllum spicatum*		Root Growth (32 d, 50% inhibition of roots weight)						40.3	C	

* Indicates values entered into Table

Assign 3 data codes, one from each of the following rows:		
A-acute	C-chronic	
S-static	R-static/renewal	F-flowthrough
U-unmeasured nominal concentration	M-measured concentration	

P Primary study	S Secondary Study	U Unacceptable Study

TLm- (median tolerance limit) This is the concentration at which acute toxicity ceases, usually taken as the concentration at which 50% of the population of test organisms can live for an indefinite time. This endpoint is now commonly known as an LC50.

[a] Converted using a molecular weight of 10.812 g/mol

[b] Chronic toxicity data points were not used for iPWQG development as these data points were considered outliers as other scientists and studies have not been able to reproduce these low values using similar conditions and species (Moss and Nagpal, 2003)

P* Classifed as primary by the BC MOE

S* Classifed as secondary by the BC MOE as test conditions were not adequately reported

? Not classifiable

NA Report was not available at all, or not available in English