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MINISTRY OF WATER, LAND AND AIR PROTECTION

Ambient Water Quality Guidelines for Boron

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Summary of Recommended Guidelines

Table I. Recommended Guidelines

Drinking water	5.0 mg B/L
Freshwater aquatic life	1.2 mg B/L
Marine aquatic life	1.2 mg B/L
Wildlife	5.0 mg B/L
Irrigation	Depends upon crop (see Table II)
Livestock watering	5.0 mg B/L

Table II. Recommended Irrigation Water Guidelines

Tolerance	Concentration of B in irrigation water (mg/L)	Agricultural Crop
Very sensitive	<0.5	blackberry
Sensitive	0.5 – 1.0	peach, cherry, plum, grape, cowpea, onion, garlic, sweet potato, wheat, barley, sunflower, mung bean, sesame, lupin, strawberry, Jerusalem artichoke, kidney bean, lima bean
Moderately sensitive	1.0 – 2.0	red pepper, pea, carrot, radish, potato, cucumber
Moderately tolerant	2.0 – 4.0	lettuce, cabbage, celery, turnip, Kentucky bluegrass, oat, corn, artichoke, tobacco, mustard, clover, squash, muskmelon
Tolerant	4.0 – 6.0	sorghum, tomato, alfalfa, purple vetch, parsley, red beet, sugar beet
Very tolerant	6.0 – 15.0	asparagus

1. Introduction

1.1. Physical and Chemical Properties

Boron (B) is a naturally occurring dark brown/black substance found throughout the environment. It only occurs in combined form, usually as borax, colemanite ($Ca_2B_6O_{11}$-$5H_2O$), boronatrocalcite ($CaB_4O_7NaBO_2$-$8H_2O$) and boracite ($Mg_7Cl_2B_{16}O_{30}$) (Eisler, 1990). It belongs to Group 13 on the periodic table and has properties which are borderline between metals and non-metals. It is a semiconductor rather than a metallic conductor and it is more related chemically to silicon than to aluminium, gallium, indium, or thallium (Winter, 1998). Its atomic weight is 10.811 and is in its solid state at 298°K. Boron's melting point is 2349°K and boiling point is 4200°K.

1.2. Production and Uses

Deposits of boron mineral are found in three major belts - the Mojave Desert in California, the plateau of the Alpine-Himalayan system and the high plateau of the Andes - and are associated with volcanic activity or where marshes or lakes have evaporated under arid conditions. Major exporters of boron are the United States, Turkey, Argentina, China, Chile and Russia (SRI Consulting, 1996). Importers of boron include Western Europe, Japan, Brazil, Australia, Canada and Eastern Europe (SRI Consulting, 1996).

Boron is used in a variety of products including glass and glass products, cleaning products, agrochemicals, insecticides, flame-proofing compounds, corrosion inhibitors and antiseptics. Boron compounds are also used in treating skin cancer resulting in complete disappearance of melanoma without substantial side effects (Mishima, 1989).

2. Environmental Occurrences and Concentrations

2.1. Sources

2.1.1. Natural Sources

The highest concentrations of boron are found in sediments and sedimentary rock, particularly clay rich marine sediments. The high boron concentration in seawater, which averages around 4.5 mg B/L, ensures that marine clays are rich in boron relative to other rock types (Butterwick *et al.*, 1989; World Health Organisation, 1998). Boron is released into the environment very slowly and at low concentrations by natural weathering processes. This amounts to approximately 360 000 tonnes of boron per year world-wide (Butterwick *et al.*, 1989). Thermal springs in Greece have been reported to have a boron concentration of 43 mg/kg (fresh weight) (Eisler, 1990). Yamamoto *et al.*(1973) reported that boron in marine zooplankton of various species ranged from 18 to 216 mg/kg (dry matter) and seaweed averaged 106 mg/kg.

Boron can also be found naturally in soils at concentrations of 5 to 150 parts per million (ppm) (Information Ventures Inc., 1995).

2.1.2. Anthropogenic Sources

Anthropogenic sources of boron in the environment include sewage sludge and effluents, coal combustion, glass, cleaning compounds and agrochemicals.

Sewage waters in Scandinavia have a boron concentration of 0.4 to 0.7 mg/kg (fresh weight) (Eisler, 1990). Boron concentrations in wastewater treatment plant effluent are estimated to range from 0.1 to 2.8 mg/L (Dyer and Caprara, 1997). In the United States, coal fired power plants are significant sources of boron. At the Chalk Point Power Plant, Maryland, the boron concentration in the coal was 13 mg/kg (ash weight), in the bottom slag it was 19 mg/kg (ash weight) and in the fly ash it was 33 mg/kg (ash weight) (Eisler, 1990). At Four Corners Power Plant, New Mexico, the boron concentrations in the coal, bottom slag and fly ash were 92 mg/kg (ash weight), 120 mg/kg (ash weight) and 240 mg/kg (ash weight), respectively (Eisler, 1990).

Boric acid or borax are essential in glass products such as heat resistant glass, insulation glass fibre, textile glass fibre, optical glass and some container glass. The amount of borates in these products ranges from 0.5 to 23% of the total weight depending on the properties required (Butterwick *et al.*, 1989). Glass products use 53.6% of the boron consumption in the United States, and 32.7% in Western Europe (Butterwick *et al.*, 1989).

Cleaning and washing products also use boron compounds. In North America, boron is mostly used as a washing aid and softener where ten percent of boron consumption is used in the cleaning industry (Butterwick *et al.*, 1989). In Western Europe, sodium perborate is used as a bleaching agent in soap and detergent. Over 41% of their boron consumption is in cleaning products (Butterwick *et al.*, 1989).

Boron, an essential trace element for plant growth, is often added to crops in a fertiliser. In higher concentrations, it can also be used as a non-selective herbicide for weed control, insecticide, algaecide in water treatment and as a timber preservative. The United States uses approximately 5% of its boron consumption in the agrochemical field (Butterwick *et al.*, 1989).

Other uses include enamels and glazes, and fire retardants.

2.2. Residues

2.2.1. Water

Because boron naturally occurs in the environment, boron residue will likely find its way into waterbodies. Generally, however, environmental concentrations found in surface water are below levels identified as toxic to aquatic organisms. In British Columbia (BC), median values for boron in surface water are about 0.01 mg/L. Boron in Canadian coastal marine waters ranges from 3.7 to 4.3 mg/L (Health Canada, 1990).

In a study of British Columbia groundwater, Wagner (1996) found that the total boron concentration ranged from 0.014 mg/L to 4.05 mg/L, with a median of 0.069 mg/L (sample size 53) and 90th percentile of less than 0.58 mg/L. For dissolved boron, the minimum detected concentration was 0.0056 mg/L, the maximum was 4.15 mg/L and the median was 0.02 mg/L (sample size 84). Ninety percent of the samples were less than 0.54 mg/L (Wagner, 1996). Between 1992 and 1993, groundwater in British Columbia's Fraser Valley was monitored for 33 metals (Carmichael, 1995, Wagner, 1996). Total and dissolved boron were measured in 245 samples. In 180 of these samples, total boron was not detected, and 92 samples did not detect dissolved boron. The method detection concentrations for total and dissolved boron were 0.04 mg/L and 0.008 mg/L, respectively. The minimum concentration was below the detection limit and the maximum was 0.86 mg/L. Ninety percent of the samples measured total boron less than 0.12 mg/L. The minimum concentration for dissolved boron was below the method detection limit, the maximum was 0.862 mg/L and the median was 0.011 mg/L. The 90th percentile concentration was 0.085 mg/L (Carmichael, 1995). The results of Wagner (1996) and Carmichael (1995) are shown in Tables 1 and 2.

Table 1. Descriptive Statistics for concentrations of boron in British Columbia groundwater (Wagner, 1996)

	MDC* (mg/L)	# Samples	# Non-Detects	Minimum (mg/L)	Maximum (mg/L)	Median (mg/L)	Mean (mg/L)	90th percentile (mg/L)
Total	0.04	53	17	0.014	4.05	0.069	0.34	0.58
Dissolved	0.008	84	17	0.0056	4.15	0.02	0.28	0.54

*Method Detection Concentration

Table 2. Descriptive statistics for concentrations of boron from the Fraser Valley Groundwater Monitoring Program (Carmichael, 1995)

	MDC* (mg/L)	# Samples	# Non-Detects	Minimum (mg/L)	Maximum (mg/L)	Median (mg/L)	Mean (mg/L)	90th percentile (mg/L)
Total	0.04	245	180	ND**	0.86	ND	0.06	0.12
Dissolved	0.008	245	92	ND	0.862	0.011	0.044	0.085

*Method Detection Concentration

** Not Detectable

In surface waters, Europe generally has low boron environmental concentrations, ranging from 0.001 mg/L up to a maximum recorded of 2.0 mg/L in Germany. All recent published data (post-1978) show boron levels to be lower than 1.0 mg/L (Butterwick, *et al.*, 1989). Levels of boron in US freshwater tend to average about 0.1 mg/L, however, they are higher - between five and 15 mg B/L - in the western US. This is due to weathering of boron rich formations and deposits (Butterwick, *et al.*, 1989).

Anthropogenic sources of boron enter the water via drainwater from irrigation and agriculture, and municipal solid waste compost. In some areas, sewage sludge is used as a fertiliser for agriculture land, and municipal wastewater has been used to irrigate crops. Boron residues in the environment have been found from these sources (Page, 1974; Ames, 1976; Cook *et al.*, 1994; Van Haute, 1983; Bartolino *et al.*, 1993).

According to Paveglio *et al.*(1992), subsurface agricultural drainwater used for marsh management has resulted in trace element contamination of aquatic bird food chains in central California. It was found that birds living on marshland had higher levels of selenium and boron at the end of the 1985 to 1986 wintering period than at the beginning, indicating that the marshland was a major source of contamination in the bird population. Elevated boron levels have also been found in shallow groundwater in the San Joaquin Valley, California due to agriculture drainwater (Swain, 1990; van Schilfgaarde, 1990). Grady and Fisher-Weaver (1988) found that groundwater in industrial and commercial areas had higher specific conductance, pH, carbon dioxide, calcium, magnesium, chloride bicarbonate, dissolved solids, strontium and boron concentrations relative to undeveloped areas.

2.2.2. Sediments and Soils

Boron retention in soil depends on boron concentration in the soil solution, soil pH, texture, organic matter, cation exchange capacity, type of clay and mineral coating on the clay (Butterwick *et al.*, 1989). The degree of boron fixation is influenced by moisture content, wetting and drying cycles and temperature. Research suggests that less than 5% of the soil boron is available for plants. After a 2 year experiment using *Sorghum vulgare sudanese* Adriano *et al.* (1988) found that initial differences between the effects of the boron sources (e.g. sodium tetraphenylboron, diphenylboric acid and boric acid) on biomass, plant boron concentration, plant boron uptake and hot water extractable boron disappeared after the first harvest. However, extractable boron concentrations from soils and plants tended to decrease more gradually in loamy sandy soil than in sandy soil (Adriano *et al.*, 1988).

Boron residues have also been found in the environment near coal and strip mining operations. Occasionally, they have been high enough to affect sensitive crops (Seierstad *et al.*, 1983; Severson and Gough, 1983).

A study on bottom sediments in uncontaminated lakes in British Columbia found that boron concentrations ranged from 2.83 mg/kg (dry weight) to 20.5 mg/kg (dry weight)(Rieberger, 1992). Larger amounts of boron were found in sediments of lakes in the less mountainous areas.

In British Columbia, boron is considered to be deficient in most soils other than those in the Peace River area. The optimum soil test levels are as follows:

mineral soils (<15% organic matter)	0.8-2.0 mg/kg
organic soils (15 - 25% organic matter)	1.0-2.5 mg/kg
organic soils (25 - 50% organic matter)	2.0-5.0 mg/kg
organic soils (>50% organic matter)	3.0-15.0 mg/kg

The recommended extraction method in British Columbia is hot water with measurements by colormetric or ICAP-AES.

Over the last few years, the Ministry of Environment, Lands and Parks collected background soil quality data for selected metals from its administrative regions throughout the province. Boron statistics are found in the table below.

Table 3. Boron concentrations in soils throughout British Columbia (Ministry of Environment, Lands and Parks, 2000)

Region	Sample	Minimum (μg/g)	Maximum (μg/g)	Mean (μg/g)	Median (μg/g)	95th percentile (μg/g)
Lower Mainland	20	1.0	20.0	7.3	6.5	20.0
Vancouver Island	20	1.0	20.0	4.3	1.0	10.0
Southern Interior	20	1.0	20.0	4.2	3.0	8.5
Kootenay	20	2.0	35.0	13.0	10.0	30.0
Cariboo	20	3.0	20.0	9.3	9.0	15.0
Omineca Peace	20	3.0	90.0	30.0	26.0	75.0

2.2.3. Biota

The Kesterson National Wildlife refuge in California was the recipient of contaminated agricultural drainwater (Schuler, 1987; Eisler, 1990) and, as a consequence, boron occurred at high concentrations in plants, insects and fish compared to a nearby control area. At this wildlife refuge Schuler (1987) reported a boron concentration in aquatic insects between 43 to 186 mg/kg dry weight compared to a concentration in the control area of 12 to 32 mg/kg dry weight. He also reported a boron concentration in the seeds of widgeongrass (*Ruppia maritima*) of 1 860 mg/kg dry weight, whereas the seeds in the control area had a concentration of 36 mg/kg dry weight.

A study conducted by Seiler *et al.*(1990) investigated the quality of irrigation drainage in and near the Humboldt Wildlife Management Area, Nevada to see if it caused or had the potential to cause harmful effects on human health, fish and wildlife or to impair beneficial uses of water. Boron was one of the constituents that equalled or exceeded baseline concentrations or recommended standards for protection of aquatic life or propagation of wildlife in water and biota. The State Water Quality standard for boron in Nevada is 1.0 mg/L for all classes of water (EPA, 1988). A similar study in the Stillwater Wildlife Management Area, Nevada by Hoffman *et al.*(1990b) found comparable results.

3. Environmental Fate and Persistence

Boron is a naturally occurring element in the environment and its worldwide production is at the same order of magnitude as natural weathering (Butterwick *et al.*, 1989). It has been estimated that 360 000 tonnes worldwide of boron is mobilised each year through natural weathering (Butterwick *et al.*, 1989). However, Butterwick *et al.* explain that since boron is tied up in many products, especially glass and glass products, it can be concluded that the larger input of available boron to the environment will likely be from natural weathering than from anthropogenic sources.

Boron's mobility in soils depends on soil acidity and rainfall. Boron is less persistent in light textured acidic soils and in areas with high rainfall because of its tendency to leach. This explains why in arid climates, boron toxicity is more of a problem than in temperate climates.

4. Bioaccumulation and Biomagnification

Bioaccumulation and biomagnification of boron in the environment is not clearly understood. There are numerous studies indicating no evidence of either of these, as well as studies indicating evidence of such action.

In general, the literature suggests that aquatic environments are not likely to experience boron bioaccumulation or biomagnification (Wren *et al.*, 1983; Butterwick *et al.*, 1989). In particular, studies performed by Thompson *et al.*, (1976) found no evidence of active bioaccumulation of boron in sockeye salmon (*Oncorhynchus nerka*) tissues or Pacific oyster (*Crassostrea gigas*). In the salmon, they found that tissue boron levels were not vastly different from water boron levels. In the Pacific oyster, it was apparent that tissue concentrations approximated the levels in the water within 36 days exposure. However, following the cessation of dosage, tissue boron levels returned to background levels by the 71st day of the study.

It has been found that migratory and resident birds bioaccumulated boron in their tissues, apparently from irrigation drainwater contamination. Setmire *et al.*(1990) conducted biological sampling and analysis that showed drainwater contaminants such as selenium, boron and DDE were accumulating in tissues of migratory and resident birds using the food sources in the Imperial Valley and Salton Sea, California. Boron concentrations were at levels that potentially could cause reduced growth in young. Boron appears to bioaccumulate in mammals, as seen from studies by Weir and Fisher (1972) and Beyer *et al.*(1983). Weir and Fisher (1972) found that toxic effects of boron included male infertility in rats and dogs due to accumulation and cytotoxic effects on germinal tissues in the testes with over 1 000 mg/kg boron equivalents (in diet). Beyer found that boric acid accumulated in the brain, spinal cord and liver after ingestion.

5. Carcinogenicity, Mutagenicity and Teratogenicity

The U.S. Environmental Protection Agency classifies boron as a Group D element, meaning that there is inadequate or no human and animal evidence of boron carcinogenicity.

There have, however, been numerous studies linking boron to teratogenicity. Egg injection studies have indicated potential embryo toxicity and teratogenicity (Birge and Black, 1977; Landauer, 1952; Schowing and Ceuvas, 1975).

Beyer *et al.*(1983) found that boric acid or sodium tetraborate in the diet causes growth retardation in mammals. Birge *et al.*(1983) administered boric acid and borax to fish and amphibian species to find substantial frequencies of teratogenisis. Boron induced teratogenisis in trout ranged from 5% at 0.001 mg/L to 26% at 1.0 mg/L.

6. Raw Water for Drinking Water Supply

6.1. Toxicity

Although boron is an essential nutrient for higher plants, it is not currently considered essential for mammals as it has not been possible to establish that deficiency impairs biological function. However, it is thought that low dietary levels protect against fluorosis and bone demineralisation and may indirectly influence calcium, phosphorus, magnesium and cholecalciferol (vitamin D3) metabolism (Heath Canada, 1990; Eisler, 1990). In high doses, though, boron can be toxic.

Korolev *et al.*(1989) found that intake of water with 250 mg/L of boron may lead to structural changes of the thyroid at the tissue, cellular and subcellular levels. Depending on the dose, boron taken orally by humans has caused a range of effects from minor symptoms to death. Many of the findings of boron toxicity to newborn infants have been a result of the accidental contamination or addition of a boron compound to infant formula or diapering powder. Siegel and Wason (1986) reported that one to three grams of boric acid, or 0.3 to 0.8 grams of boron per body weight was lethal to newborns. Four and one half to 15 grams of boric acid (equivalent to 1.25-4.2 g/kg body weight (as boric acid)), in accidentally contaminated formula at a newborn nursery caused death preceded by severe symptoms (O'Sullivan and Taylor, 1983; Siegel and Wason, 1986). Five to six grams of borates (0.7 g/kg body weight (as borates)) was fatal to infants, and fifteen to twenty grams of boric acid (0.25-0.3 g/kg body weight (as boric acid)) was fatal to adults (EPA, 1975; Siegel and Wason, 1986; Dixon *et al.*, 1976). O'Sullivan and Taylor (1983) reported that despite a recommendation from the Pharmaceutical Society of Great Britain that baby products containing boron compounds should not be sold because of hazards to infants, pacifiers and other products were indeed sold. As a result, infants, age six to sixteen weeks were given pacifiers dipped in a proprietary borax (107 g/L (as borax)) and honey compound for about a one month exposure period. The infants received an estimated three to nine grams of borax. Some developed seizure disorders characterised by vomiting, loose stools, irritability and diarrhoea. Elevated blood boron levels of 2.6 to 8.5 mg B/L were found versus less than 0.6 mg B/L in the controls. When the preparation was withheld, seizures stopped and children remained well for at least five years.

6.2. Summary of Existing Guidelines

The current interim maximum acceptable concentration for boron in drinking water, from Health Canada, is 5.0 mg/L (Health Canada, 1996). The National Academy of Sciences (1980) recommends a guideline of less than 1.0 mg B/L for drinking water. In the USSR, the guideline is less than 0.5 mg B/L (Seal and Weeth, 1980), and according to Puls (1994), the recommended maximum levels for humans is less than 5.0 mg B/L.

According to the US Environmental Protection Agency (EPA), Office of Water (1996), the reference dose of boron for a 70kg adult is 0.9 mg/kg/day. This is an estimate of a daily exposure to the human population that is likely to be without appreciable risk of deleterious effect over a lifetime.

Several individual states in the US have set drinking water guidelines for boron ranging from 0.006 mg/L (Colorado Public Health) to 1.0 mg/L (see Table 13).

6.3. Recommended Water Quality Guidelines for Drinking Water

Health Canada recommended an interim maximum acceptable concentration for boron in drinking water of 5.0 mg/L.

6.3.1. Rationale

The maximum acceptable concentration was set because the availability of practicable treatment technology is inadequate to reduce boron concentrations in Canadian drinking water supplies to less than 5.0 mg/L. Because boron concentration levels in British Columbia's surface and ground water are less than this value, boron toxicity is not expected to pose a significant risk to drinking water. The Health Canada value was adopted in this document.

7. Aquatic Life

7.1. Toxicity to Aquatic Biota

The toxic effect of boron to aquatic organisms is governed by several factors that include: form and concentration of boron, type and characteristics (e.g. life stages) of organism, and period and type of exposure to boron (acute or chronic). For example, Birge and Black (1977) found that embryonic stages in fish and amphibians were more sensitive to boron compounds than the early post-hatched stages. Butterwick *et al.*(1989) found that environmental factors such as reconstituted water showed greater toxicity to trout embryo larval stages than if they were exposed to boron in natural water.

Although the form of boron tested varies among different studies, the predominant form of boron in most natural freshwater systems is undissociated boric acid (Butterwick *et al.*, 1989).

7.2. Freshwater Biota

7.2.1. Fish and Amphibians

Effects of boron have been studied on a variety of freshwater fish, ranging from goldfish to rainbow trout (See Table 7). Figures 1 and 2 graphically show boron toxicity to freshwater vertebrates and amphibians. At lower concentrations, boron has been found to be beneficial to some freshwater organisms. The addition of 0.4 mg B/L to ponds used for raising carp found an increased production by 7.6% (Avetisyan, 1983).

Birge and Black (1977) completed an extensive study on the sensitivity of vertebrate embryos to borax and boric acid. The freshwater fish studied were goldfish (*Carassius auratus)*, rainbow trout (*Oncorhyncus mykiss)* and channel catfish (*Ictalurus punctatus)*. Depending on the sensitivity of the species, the tests were initiated at 50 to 300 mg/L boron and continued at 2- to 10- fold dilution until LC_1 and LC_{50} values were reached. Boron treatment was initiated subsequent to fertilisation and maintained continuously through 4 days post-hatching, giving exposure of 28 days, 9 days and 7 days. The culture medium was prepared from distilled, double deionized water and bioassays were conducted using the continuous flow system. The results of their findings are outlined in the Table 4. Birge and Black (1977) did not find a statistical, consistent difference in the toxicity of borax and boric acid with water hardness for any aquatic species at 4 days post-hatch. However, they did observe consistent interactions that seemed to indicate that boron toxicity was a function of its form, organism and lifestage. For example, borax was more toxic to amphibian embryos and larvae at LC_1 and LC_{50} exposure levels whereas fish developmental stages were more sensitive to boric acid at LC_1 concentrations due to higher frequencies of teratogenisis. Please refer to Table 4.

Table 4. LC_{50} and LC_1 values for Goldfish, Rainbow Trout, Channel Catfish, Leopard Frog and Fowler's Toad

		LC_{50} Values (mg B/L)		LC_1 Values (mg B/L)	
Species	**Water Hardness**	**Borax**	**Boric Acid**	**Borax**	**Boric Acid**
Goldfish	soft	65.0	46.0	1.40	0.60
	hard	59.0	75.0	0.90	0.20
Rainbow Trout	soft	27.0	100.0	0.07	0.10
	hard	54.0	79.0	0.07	0.001
Channel Catfish	soft	155.0	155.0	5.5	0.50
	hard	71.0	22.0	1.7	0.20
Leopard Frog	soft	47.0	130.0	5.00	13.00
	hard	54.0	135.0	3.00	22.00
Fowler's Toad	soft	--	145.0	--	25.00
	hard	--	123.0	--	5.00

Black *et al.* (1993) found that embryo larval stages of trout are among the most sensitive aquatic organisms to boron. In 1983, Birge *et al.* reported boron-induced teratogenesis in trout ranging from 5% at 0.001 mg/L to 26% at 1.0 mg/L. In the 1993 study, however, Black *et al.* (1993) found that boron present in natural water was less toxic than when administered in reconstituted water in the laboratory. The variation may be due to differences in the natural composition of the water from diverse regions. This natural/reconstituted water variation in boron toxicity was also discussed in the Butterwick *et al.*(1989) report.

The British Columbia Ministry of Environment, Lands and Parks (MELP) conducted studies on coho salmon and rainbow trout to assess boron toxicity in well water (100 mg/L $CaCO_3$ hardness), hard (250 mg/L $CaCO_3$ hardness) and soft (25 mg/L $CaCO_3$ hardness) water. The 96h-LC_{50} for coho was 304.1 mg/L, 477.1 mg/L and 357.4 mg/L for well, hard and soft water respectively. For rainbow trout, the 96h-LC_{50}'s were 379.6 mg/L (well water), 334 mg/L (hard water) and 438.7 mg/L (soft water) (MELP, 1996).

7.2.2. Invertebrates

Studies on the effects of boron on several freshwater invertebrates can be found in Table 7 and are graphically represented in Figure 2.

In acute toxicity evaluations of waterborne sodium tetraborate, Maier and Knight (1991) found that the 48h-LC_{50} of a freshwater midge *Chironomus decorus* was 1376 mg B/L. They also found a 48h-LC_{50} for *Daphnia magna* of 141 mg B/L. Lewis and Valentine (1981) performed a 48 hour static acute and 21 day static renewal chronic tests on *Daphnia magna* using boric acid and distilled water. The acute toxicity 48h-LC_{50} was 226 mg B/L with a no kill concentration of less than 200 mg B/L. The chronic 21-d LC_{50} was found to be 53.2 mg B/L. This was based on 100%, 32% and 14% adult mortality observed in the 106, 53 and 27 mg/L boron test waters. Control mortality was 9% with boron concentrations greater or equal to 13 mg/L. The total young produced for 21 days progressively declined and the number of offspring produced in waters containing 53 mg/L boron was about 70% lower than the control. Gersich (1984) found a 21d-LC_{50} of 52.2 mg B/L using *Daphnia magna*.

The British Columbia MELP (1996) study reported a 48h-LC_{50} for *Daphnia magna* of 52.4 mg/L in well water of 100 mg/L $CaCo_3$ hardness. The Daphnia 21d chronic LOEC was 25.4 mg/L (well water) and NOEC was 13.1 mg/L (well water). In hard water (250 mg/L $CaCO_3$), the 48h-LC_{50} was 139.2 mg/L and in soft water (25 mg/L $CaCO_3$), it was 21.3 mg/L. The 21d chronic LOEC in the hard water was 26.4 mg/L and NOEC was 12.4 mg/L (MELP, 1996). Studies conducted for boron toxicity on *Hyallela azteca* concluded a 10d-LC_{50} of 291.3 mg/L (well water), 333.6 mg/L (hard water) and 28.9 mg/L (soft water) (MELP, 1996). For *Chironomid tentans*, the well water, hard and soft water 10d-LC_{50}'s were 118.0 mg/L, 137.7 mg/L and 157.3 mg/L, respectively (MELP, 1996).

7.2.3. Algae and Macrophytes

Toxicity data for a variety of freshwater algae and macrophytes were available from the literature (Table 7) and are shown graphically in Figures 3 and 4.

Rooted macrophytes tended to be the most boron-sensitive aquatic species (Maier and Knight, 1991). Nobel *et al.*(1983) found that growth was inhibited in the submerged macrophytes *Elodea canadensis* when exposed to 1.0 mg B/L.

Frick (1985) found that duckweed *(Lemna minor)* tolerated between 0.01 and 0.02 mg/mL elemental boron in the growth medium at pH 5.0 without being inhibited. At 0.2 mg/mL, boron was toxic after three days of exposure. He also found that pH seemed to affect the bioaccumulation of boron in duckweed. At a pH of 4.0 and in the presence of 0.02 mg B/L for 7 days, the plants accumulated 0.093 mg B/g fresh weight (148% of control). At pH 7.0, the plants accumulated 0.257 mg B/g fresh weight (525% of control).

Martinez *et al.*(1986) performed studies on the effect of boron (as boric acid) on the blue green algae *Anacystis nidulans.* They found that a concentration of 75 mg B/L significantly decreased growth and chlorophyll content. At a concentration of 100 mg B/L, there was a decrease in protein content causing inhibition in nitrate uptake and nitrate reductase activity. There was also a decrease in chlorophyll content and photosynthesis inhibition within 72 hours. Mateo *et al.*(1987) reported similar results. Studies involving the green algae *Chlorella pyrenoidosa* found that 50 to 100 mg B/L altered cell division and amino acid activity after 72 hours. Giant cells also formed with increased nitrate and protein (Maeso *et al.*, 1985). At concentrations greater than 100 mg B/L, it was totally inhibitory for cell division and biomass synthesis in 72 hours (Maeso *et al.*, 1985).

British Columbia MELP studies on *Selenastrum capriconutum* concluded a 72h-IC_{50} (inhibitory concentration) of 13.9 mg/L (MELP, 1997).

7.3. Marine Biota

An overview of studies on the effects of boron on marine aquatic life is in Table 8.

7.3.1. Fish

Boron toxicity data for marine vertebrates are represented graphically in Figure 6.

Taylor *et al.*(1985) studied the effects of a variety of metals on *Limanda limanda* (Dab) and found a 24h-LC_{50} concentration of 88.3 mg B/L. Thompson *et al.*(1976) performed static renewal studies using seawater and sodium metaborate on underyearling and alevin coho salmon (*Oncorhynchus kisutch)* (1.8-3.8g in weight). They found the 96h-LC_{50} was 40.0 mg B/L and the 283h-LC_{50} was 12.2 mg/L. Hamilton and Buhl (1990) conducted static acute toxicity tests on coho salmon in brackish water using boric acid to find the 24h-LC_{50} at greater than 1 000 mg B/L and the 96h-LC_{50} at 600 mg B/L. They found similar results when tests on chinook salmon (*O. tshawytscha*) were performed.

Studies performed on coho salmon by British Columbia MELP found a 96h-LC_{50} of 122.6 mg/L (MELP, 1996).

7.3.2. Invertebrates

Information regarding the effects of boron on marine invertebrates was limited. Data that was collected is graphically represented in Figure 7.

Kobayashi (1971) found a sea urchin (*Anthocidaris crassispina)* exposed to 37.0 mg B/L had normal development, whereas a concentration of 75 mg B/L was fatal.

Thompson *et al.*(1976) found boron uptake in Pacific oysters (*Crassostrea gigas*) was slow as the 8 day sampling failed to show an increase in tissue boron levels when exposed to 10 mg B/L above background levels. Prior to exposure, tissue boron levels ranged from 3.67 to 4.13 mg/kg.

British Columbia MELP conducted boron toxicity tests on purple sea urchins (*Strongylocentrus droebachiensis*) and sand dollars (*Eohaustorius washingtonianus*) and concluded an EC_{50} of 503.3 mg/L and LC_{50} of 847.7 mg/L respectively (MELP, 1997; MELP 1996).

7.3.3. Algae and Macrophytes

Subba Rao (1981) found that a concentration of 30 mg B/L on ten species of marine phytoplankton (unialgal cultures) caused a reduction in photosynthesis for half the species after five days. Boric acid at concentrations of five to 10 mg B/L appeared to be non-toxic to nineteen marine algae species; however, levels of 10 to 50 mg B/L were thought to cause shifts in population composition (Antia and Cheng, 1975). They also found a reduction in growth rate for 26% of the 19 marine phytoplankton species (axenic cultures) they tested at concentrations of 50 mg B/L.

7.4. Interactions

For the most part, there did not seem to be any significant interaction between water hardness and boron toxicity (Laws, 1981; Birge and Black, 1977; Hamilton and Buhl, 1990; Maier and Knight, 1991). Butterwick *et al.*(1989) found that the effect of hardness on boron toxicity was present but it was not consistent. For example, embryos and larvae of rainbow trout displayed a greater toxic reaction to borax in soft water, whereas boric acid was most toxic to rainbow trout life stages in hard water.

British Columbia MELP found no correlation between hardness and toxicity for coho salmon, rainbow trout and Chironomid test outcomes, but did find decreasing toxicity with increased hardness for Daphnia and Hyalella.

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

7.5. Summary of Existing Guidelines

Please refer to Table 14 and Table 15 for an overview of existing boron guidelines for freshwater and marine aquatic life.

7.5.1. Freshwater Aquatic Life

The South African national boron criteria for coldwater-adapted species is 0.01 mg/L to protect from acute effects (acute effect value (AEV)) and 0.001 mg/L to protect from chronic effects (chronic effect value (CEV)) (Roux *et al.*, 1996). The AEV refers to the concentration at and above which a statistically significant acute adverse effect is expected to occur. If the AEV is exceeded for a limited and short period of time, aquatic organisms should not be permanently affected and the population should recover. It should be viewed as a danger or reaction level. The CEV refers to the concentration limit that is safe for all or most populations even during continuous exposure. If the CEV is exceeded, fish, invertebrates, phytoplankton and aquatic plant communities in freshwater ecosystems may not be protected against unacceptable long term and short term effects. A safety factor of 1 000 was used in determining the criteria due to the lack of data.

Australia and New Zealand adopted a freshwater high reliability trigger value for boron of 0.37 mg/L (ANZECC, 2000). This was calculated using screened chronic freshwater data (around 30 points) from five taxonomic groups. Toxicity's were expressed as NOEC equivalents or were adjusted to NOECs by dividing by factors depending on the end-points (NOEC = MATC/2; LOEC/2.5 or E(L)C_{50}/5)(ANZECC, 2000). There was a 95% protection level with a 50% confidence. The magnitude of an assessment factor applied to the lowest NOEC was generally 10 (ANZECC, 2000). This guideline derivation is conservative as it uses NOEC data rather than the LOEC data CCME (1993) recommends.

According to the EPA (1988), 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. New York set the guideline at 10 mg/L as the criterion for Class AA (aquatic) use, and in the Mariana Islands the criterion for the protection of freshwater aquatic life is 5 mg/L. Many states have not set boron guidelines for the protection of freshwater aquatic life.

The Canadian Council of Ministers of the Environment (CCME) has not set a guideline for boron to protect freshwater aquatic life.

7.5.2. Marine Aquatic Life

Many jurisdictions have not set boron guidelines for the protection of marine aquatic life. According to the EPA (1988), Guam, the Mariana Islands and Trust Territories have set criteria for the protection of marine aquatic life at 5.0 mg/L. Puerto Rico has set the guideline at 4.8 mg/L for coastal waters for use in propagation, maintenance and preservation of desirable marine species.

The CCME has not set a guideline for boron to protect marine aquatic life.

7.6. Recommended Water Quality Guideline and Rationale for Aquatic Life

7.6.1. Freshwater Aquatic Life

It is recommended that the maximum concentration of boron for the protection of freshwater aquatic life should not exceed 1.2 mg B/L.

7.6.1.1. Rationale

Birge and Black (1977) studied the embryo sensitivity of rainbow trout, channel catfish, goldfish, and amphibians to boron compounds. The most sensitive species was the rainbow trout (*Oncorhyncus mykiss)*, with a 28d-LOEC of 1.00 mg B/L. Birge and Black also studied boron toxicity on rainbow trout in their 1981 study and found a 32d-LOEC of 0.1 mg B/L. Similar results were observed in the Black *et al.* (1993) report. In 1983, Birge *et al.* found 5% of rainbow trout had boron induced teratogenesis at levels of 0.001 mg/L.

Compared with other research, the Birge and Black studies have consistently found very low concentration toxicity levels for a variety of aquatic species, yet cannot be reproduced by other scientists and studies using similar conditions and species. These data are represented by solid triangles that fall below the recommended guideline in Figure 1. The data appear to be outliers and, therefore, were not considered in the development of the British Columbia guideline.

British Columbia MELP (1997) found a lowest effect level for growth inhibition on *Selenastrum capricornutum* of 12.3 mg/L. Because this was a chronic study that produced primary data a safety factor of 0.1 was used to derive the interim guideline. The safety factor is consistent with the CCME and British Columbia protocols for guideline derivation.

Nobel *et al* (1983) found that growth of *Elodea canadensis* was inhibited at a boron concentration of 1.0 mg B/L. This paper was not used in the guideline derivation because it was considered a secondary study since test conditions were not adequately reported. Also, the original work (a Ph.D thesis in German) could not be obtained from the University of Hohenheim, Germany.

7.6.2. Marine Aquatic Life

It is recommended that the maximum concentration of boron for the protection of marine aquatic life should not exceed 1.2 mg B/L.

7.6.2.1. Rationale

The guideline is based on the critical study by Thompson *et al.* (1976) that looked at the toxicity, uptake and survey studies of boron in the marine environment. This study was performed on the west coast of British Columbia. They found the most sensitive species was coho salmon (*Oncorhynchus kisutch)*, with a 283h-LC_{50} of 12.2 mg B/L. They used a static renewal (daily) test and monitored dissolved oxygen, pH and temperature in all tanks throughout the test. This study is very relevant to British Columbia as it was carried out using local coastal waters and species. A safety factor of 0.1 was used to derive the guideline due to the paucity of data in the marine environment.

8. Wildlife

8.1. Toxicity

8.1.1. Mammals

Boron toxicity to mammals is summarised in Table 9.

Puls (1994) produced an extensive paper on mineral levels in animal health. Boron has not been shown to perform an essential function in cattle, but is considered to be essential at very low levels in goats. He found that boron appears to be of relatively low toxicity to animals, however, higher levels appear to have an adverse effect on phosphorus metabolism in cattle. In cattle, the lethal dose is approximately 200 to 600 mg B/kg body weight, and consumption of fertiliser containing 20.5% boron has poisoned cows. Signs of toxicity in cattle include inflammation and edema of the legs, reduced feed consumption, reduced weight gain, reduced hematocrit and hemoglobin levels, depression, lethargy, mild shivering or fluttering of eyelid muscles, stiffness and spastic gait with staggering and falling into lateral recumbency.

As mentioned earlier, boron is now considered to be an ultra trace element for goats, as it may influence hormone synthesis and second messenger activity (Puls, 1994). A single dose of 3 600 mg/kg body weight from fertiliser containing 20.5% boron caused death in goats in eight hours. Toxic signs occurred at 1 800 mg B/kg body weight and symptoms included anorexia, depression, drowsiness, profuse urination with the inability to drink, signs of muscle pain with slight tremors in the muscles of the ears and limbs, weakness and uneasiness on feet.

The LD_{50} for rats was 510 to 690 mg/kg body weight, as borax and 550 to 710 mg/kg body weight, as boric acid (Weir and Fisher, 1972; EPA, 1975; Dani *et al*, 1971). Sprague (1972) found that boric acid and borax have very high LD_{50} values in lab rats, suggesting a low acute mammalian toxicity. Seal and Weeth (1980) performed boron studies on lab rats and found that rats had body weights 7.8% and 19.8% less than the control group when exposed to drinking water containing boron concentrations of 150 to 300 mg/L. Lab rats taking drinking water with 300 mg/L boron were overly small in body size and had longer toenails, atrophic scrotal sacs and coarse pelages.

Puls (1994) reported the LD_{50} for dogs at 1 780 to 2 000 mg/kg bodyweight, while the maximum tolerated level of boron in the diet for horses was 150 mg/kg dry matter.

8.1.2. Birds (Wildlife)

Boron toxicity to birds (wildlife) is summarised in Table 10.

Stanley *et al.*(1996) found that 900 mg/kg dietary boron in mallard ducks caused reduced hatching success by more than 42%, duckling weight and growth was reduced and there was a 47% reduction in number of ducklings produced per female. Whitworth *et al.*(1991) exposed one day old mallard ducklings to daily boron in their diet at a dose of 100, 400 and 1 600 mg/kg for nine weeks. Seven behavioural activities - bathing, feeding, preening, resting, standing, moving and drinking - were observed. Dietary boron had an effect on five of seven behaviours. There was a decrease in bathing time and an increase in feeding and preening times. There was also an increase in resting and a decrease in alert time. Developing mallard ducklings had increased rest and supplementary warmth, and a decrease in alert time, which, in natural environments, may compromise predator avoidance and foraging strategies.

Hoffman *et al.*(1990a) studied the effects of dietary boron on mallard ducklings and found a significant delay in growth (especially in females) for the 1 600 mg/kg group compared to the control. They also found that in the higher dose group boron accumulated in the brain and liver 25 to 29 times greater than in the controls. Smith and Anders (1989) found the hatching success of fertile eggs laid by mallards fed 1 000 mg/kg (in diet) boron was reduced to 52% of the control value. Ducklings fed 1 000 mg/kg had higher mortality rates during the first week of life and their mean weight gain was lower than the controls.

8.1.3. Birds (Livestock)

Boron toxicity to birds (livestock) is summarised in Table 10.

Puls (1994) reported that a single dose LD_{50} was 3 000 mg boric acid/kg body weight for a day old chicken. He found that 250 mg/kg boron (in diet) reduced hatchability but not egg production. At 5 000 mg/kg boric acid in feed stopped egg laying in 6 days and also resulted in 10% mortality in chicks. The LD_{50} for a chicken embryo injected with boric acid was 1.0 mg B/kg body weight (Birge and Black, 1977). In ducks, Puls found that 1 000 mg/kg of dietary boron increased the mortality rate of ducklings during the first week of life. It also reduced the number of ducklings produced per female. Less than 300 mg/kg (in diet) had no effect on hatchability. Toxicity signs in both chickens and ducks included face, beak and appendicular skeleton abnormalities similar to riboflavin deficiency and feathering abnormalities.

8.1.4. Insects

Boron toxicity to insects is summarised in Table 9.

There is limited information regarding the effects of boron on insects. In general, relatively high concentrations of boron is used to control fruit flies, cockroaches, houseflies and woodboring insects. Sprague (1972) performed some studies on the effects of boron on various insects. He found that 17.5 mg B/L in a syrup was fatal to about 50% of honey bees (*Apis mellifera*), 250 to 5 000 mg B/kg diet (as boric acid) inhibited reproduction in houseflies (*Musca domestica*) and 430 mg boric acid/m^3 wood provided adequate wood protection from woodboring insects.

8.2. Interactions

Hoffman *et al.*(1991) found that several interactive effects occurred between boron and selenium, including reduction in duckling growth, and increases in plasma glutathione reductase activity, hematocrit, hemoglobin and plasma protein concentrations. The findings also suggested the potential for more severe toxicological effects of selenium and boron independently and interactively on duckling survival and development when dietary protein is diminished. However, Stanley *et al.*(1996) found no important interactions between boric acid and seleno-DL-methionine with regard to adult [mallard duck] health, reproductive success, duckling growth and survival and tissue residues of boron or selenium.

Neilsen *et al.*(1988) studied how dietary boron affected dietary aluminium. They found that aluminium seemed most toxic when dietary boron was high, and aluminium more markedly depressed growth in boron-supplemented than boron-deprived rats.

Smith and Anders (1989) reported that boron has an affinity for binding to polyhydroxy compounds, such as riboflavin, and developmental malformations produced by egg injection resemble those with riboflavin deficiency.

8.3. Summary of Existing Guidelines

Eisler (1990) proposed to apply the livestock criteria for the protection of mammalian wildlife. That is, diets should contain more than 0.4 mg B/kg dry weight but less than 100 mg/kg, and the drinking water should contain less than 5 mg B/L.

A summary of existing guidelines for wildlife can be found in Table 16.

8.4. Recommended Water Quality Guidelines for Wildlife

It is recommended that the maximum concentration of boron for the protection of wildlife should not exceed 5.0 mg B/L.

8.4.1. Rationale

There is limited data on the effects of boron on wildlife. Therefore, the use of the guideline set for livestock watering is recommended on an interim basis.

9. Irrigated Crops and Terrestrial Plants

9.1. Toxicity

Table 11 summarises the effects of boron on plants and irrigated crops.

It is generally accepted that boron toxicity is closely associated with salinity problems in hot, arid climates (Butterwick *et al.*, 1989; Nicholaichuk *et al.*, 1988, Gupta *et al.*, 1985). However, toxic levels do not occur on agricultural lands unless boron compounds have been added in excessive quantities, such as with fertiliser materials, irrigation water sewage sludge or coal ash (Eisler, 1990). Irrigation water contaminated with boron is one of the main causes of boron toxicity in plants and it is the continued use and concentration of boron in soil, especially in arid regions with high evapotranspiration, that leads to toxicity problems (Gupta *et al.*, 1985). Boron toxicity in plants is characterised by stunted growth, leaf malformation, browning and yellowing, chlorosis, necrosis, increased sensitivity to mildew, wilting and inhibition of pollen germination and pollen tube growth (Butterwick *et al.*, 1989; Eisler, 1990).

The limits between boron deficiency and toxicity are very narrow, so boron applications can be extremely toxic to some plants at concentrations that are only slightly above optimum for others (Gupta *et al.*, 1985). Butterwick *et al.* (1989) and Gupta *et al.*(1985) suggest that monocotyledons require only about one quarter as much boron for normal growth as dicotyledons, and Leguminosae and Brassicae have the highest requirement for, and tolerance to, boron. Adriano *et al.* (1988) found that plant toxicity from organic sources of boron was noted only during the first harvest of *Sorghum vulgare sudanese* while boric acid had no adverse effects. Citrus, blackberry, stone fruits, nut trees, violet and pansy seem to be the most sensitive to boron (Eisler, 1990; CCREM, 1987; Muchmore and O'Brien, 1977; Birge and Black, 1977; Lewis and Valentine, 1981). Boron deficiency or excess will result in the reduction of crop yield and/or the impairment of crop quality. Generally, boron toxicity under field conditions occurs when plant tissue concentrations exceed 0.2 mg/g (dry weight). Sensitive crops may experience toxicity will below this level (Gupta *et al.*, 1985).

Sprague (1972) found that a soil boron concentration of 1.0 mg/L provided optimal growth for corn, but at 5.0mg B/L, injury was evident. Similarly, he found a soil boron concentration of 0.03 to 0.04 mg/L to be the optimum for lemon growth, but 1.0 mg B/L caused injury. For beets, it took a soil boron solution of 15 mg/L to cause injury. Boron concentrations in soil water between 2.5 and 5.0 mg B/L were toxic to rice (Cayton, 1985).

Watson *et al.*(1994) studied five species belonging to the Atriplex genus that were grown with saline drainage water. Collected samples were analysed for several trace elements, including boron. Averaged over all species and harvests, tissue boron concentrations progressively increased with time, to an overall mean of 176 mg/kg (dry weight). This was above the maximum tolerable level recommended in feed for ruminants (150 mg/kg (dry weight)). Retana *et al.*(1993) conducted a column study in a greenhouse using soil from Kesterson Reservior, California, to assess the growth of salt and boron tolerant genotypes and to determine uptake of several trace elements (including boron). High concentrations of boron (>60 mg/kg dry weight) were found in plant shoots, perhaps high enough to pose potential food chain transfer hazards. However, despite high levels of soil salinity and boron, tall wheatgrass and alkali sacaton grass were able to persist, suggesting an ability to acclimate to the stresses.

9.2. Interactions

As stated in the previous section, boron toxicity is closely associated with salinity problems in hot, arid climates. However, Gupta and Chandra (1972) found that gypsum may reduce the boron hazard of saline water and saline sodic soil. An eighty percent dose of gypsum reduced the toxicity of sodic soil while one percent was sufficient to reduce toxicity in water.

Taylor and Macfie (1994) performed studies to see if boron alleviates the toxic effects of aluminium on plant growth but found no evidence that this happened. Varying the supply of boron had little effect on accumulation of aluminium in roots and leaves, but increasing aluminium concentrations in solution resulted in increased immobilisation of boron in roots and decreased accumulation of boron in leaves. Growth of plants with elevated boron supply resulted in higher concentrations of boron in roots and leaves without improving growth.

Butterwick *et al.*(1989) found that soil texture plays an important role in determining boron availability to plants. Clay soils have a large capacity for boron absorption and can provide a “sink” for the element. In addition, an increase in soil pH has been found to cause a reduction in boron uptake. Both temperature and light influence the rate of boron uptake – peak uptake occurs at 35°C and high irradiances increase the rate of boron uptake (Butterwick *et al.*, 1989; Eisler, 1990). Sprague (1972) found that boron uptake by plants is about four times higher at pH 4 than at pH 9, highest in a temperature range of 10 to 30^{o}C, and higher at higher light intensity. Gupta *et al.*(1985) reported similar findings.

There have been a few studies showing that nitrogen may decrease the severity of boron toxicity symptoms in cereals and citrus trees. Gupta *et al.*(1985) stated that liberal nitrogen applications are sometimes beneficial in controlling excess boron in citrus and reducing toxicity symptoms in cereals. However, there have also been studies showing these benefits of nitrogen treatment are inconclusive with wheat and barley (Butterwick *et al.*, 1989; Gupta *et al.*, 1985).

Eisler (1990) reported that visible signs of boron deficiency in corn are accentuated by calcium deficiency, and are least evident when calcium is added in excess. Gupta *et al.*(1985) reports that high levels of potassium accentuate boron deficiency and toxicity symptoms by narrowing the tolerance range, apparently by suppression of calcium activity.

9.3. Summary of Existing Guidelines

The Canadian Council of Resource and Environment Ministers (CCREM)(1987) suggested the concentration of total boron in irrigation water should not exceed 0.5 mg/L for sensitive plants, but could be as high as 6 mg/L for tolerant plants. The CCME, the current name of the CCREM, accepted the guideline for boron that was first developed in 1987 since more recent data (post-1987) did not present evidence for a change. The Ontario Ministry of the Environment (1984) recommended a guideline of 0.75 mg/L for irrigation water used continuously on all soils and 2.0 mg/L for irrigation water used up to 20 years on fine textured soils of pH 6.0 to 8.5. In Manitoba, Williamson (1983) recommends a boron concentration not greater than 0.5 mg/L for irrigation water used as a sole source on crops (i.e. greenhouse crops). On crops that receive both natural precipitation and supplemental irrigation, the concentration should be no greater than 1.0 mg/L. For the protection of medium to fine textured soils up to 20 years, the concentration should not be greater than 2.0 mg/L (Williamson, 1983). Alberta Environment (1999) adopted the guidelines set by CCREM (1987).

The US Environmental Protection Agency developed three specific boron guidelines for irrigation waters since crops show different sensitivity to boron. For sensitive crops (e.g., citrus trees) the value is between 0.3 and 1.25 mg B/L. For semi-tolerant crops, such as cereals and grains, the value is 0.67 to 2.5 mg B/L and for tolerant crops, that includes most vegetables, the guideline is 1.0 to 4.0 mg B/L (Eisler, 1990). For long term irrigation on sensitive crops, the US EPA recommended a guideline of 0.75 mg/L (EPA, 1988).

Numerous states in the US have a boron guideline value of between 0.75 mg B/L to 1.0 mg B/L (EPA, 1988; New Mexico Water Quality Control Commission, 1995; Hergert and Knudsen, 1977). In Australia and New Zealand, it was recommended that the boron concentration in irrigation waters should not exceed 0.5 mg/L (ANZECC, 2000).

Please refer to Table 17 for a summary of boron guidelines for irrigated crops.

9.4. Recommended Water Quality Guidelines for Irrigated Crops

It is recommended that the maximum concentration of boron for the protection of irrigated crops should not exceed those shown in Table 5. These guidelines depend on the sensitivity of the crops and are consistent with the CCME (1999) guidelines.

Table 5. Relative tolerance of agricultural crops to boron (CCME, 1999)

Tolerance	Concentration of B in irrigation water (mg/L)	Agricultural Crop
Very sensitive	<0.5	blackberry
Sensitive	0.5 – 1.0	peach, cherry, plum, grape, cowpea, onion, garlic, sweet potato, wheat, barley, sunflower, mung bean, sesame, lupin, strawberry, Jerusalem artichoke, kidney bean, lima bean
Moderately sensitive	1.0 – 2.0	red pepper, pea, carrot, radish, potato, cucumber
Moderately tolerant	2.0 – 4.0	lettuce, cabbage, celery, turnip, Kentucky bluegrass, oat, corn, artichoke, tobacco, mustard, clover, squash, muskmelon
Tolerant	4.0 – 6.0	sorghum, tomato, alfalfa, purple vetch, parsley, red beet, sugar beet
Very tolerant	6.0 – 15.0	asparagus

9.4.1.Rationale

The Province’s agriculture industry is widely diversified in the variety of crop species grown, from the boron-sensitive crops of blackberry, peach and strawberry to the more tolerant crops such as asparagus, carrot and tomato. However, due to the very low residual levels of boron in the surface water (0.01 mg/L) and groundwater (0.069 mg/L), boron toxicity is not expected to be an issue.

10. Livestock Watering

10.1. Toxicity

There was limited information regarding boron toxicity to livestock for drinking water in the literature. Table 12 summarizes the effects of boron on livestock.

It was thought that the ingestion of high concentrations of boron caused a decrease in the intestinal proteolytic enzyme activity and blood nitrogen in sheep (Butterwick *et al.*, 1989). Green and Weeth (1977) found that 150 to 300 mg/L boron in cattle's drinking water resulted in toxic signs within 30 days. In the same study, the author's reported that at concentrations of 29 mg B/L and higher, cattle preferred tap water to drinking water supplemented with boron compounds. At a concentration equivalent to 15.3 mg B/kg body weight daily, there was decreased food consumption, weight loss, edema, inflammation of legs and abnormal blood chemistry. Weeth *et al.* (1981) later found that 120 mg B/L (as borax) seemed to have no effect on feed or water consumption and no overt signs of toxicosis in cattle.

10.2. Summary of Existing Guidelines

There is limited information on guidelines for livestock watering. The CCME (1999) recommended a boron concentration of less than 5.0 mg/L in livestock drinking water. The US EPA recommended a maximum allowable guideline in livestock water supply of 5.0 mg B/L (Eisler, 1990). This guideline was also used in New Mexico and Kansas (New Mexico Water Quality Control Comm, 1995; EPA, 1988), and Australia and New Zealand (ANZECC, 2000).

NAS (1980) gave a maximum tolerable level of 150 mg/kg boron, as borax, in the diet of cattle and suggested that this level should be reasonable for other livestock. In a study about the effects of boron in livestock drinking water, Green and Weeth (1977) concluded that a concentration of 150 mg/L resulted in decreased hay consumption and weight loss. They also found that, at 40 mg/L, any effects to livestock would be minimal.

Puls (1994) recommended a safe level ranging from 5.0 to 30.0 mg/L in livestock drinking water.

Please refer to Table 18 for a summary of existing guidelines for livestock watering.

10.3. Recommended Water Quality Guidelines for Livestock Watering

It is recommended that the maximum concentration of boron in livestock watering should not exceed 5.0 mg/L. This is the same guideline as recommended by the CCME (1999).

10.3.1. Rationale

There were insufficient data to calculate an interim guideline for livestock species using the CCME (1993) derivation method. However, Australia and New Zealand have developed water quality guidelines for agriculture water use under the National Water Quality Management Study. They recommend that if the boron concentration in water exceeds 5.0 mg/L, the total boron content of the livestock diet should be investigated and higher concentrations in water may be tolerated for short periods of time (ANZECC, 2000). They derived this guideline based on the principles adopted by the World Health Organization and found that guideline values for various types of livestock ranged from 5.8 (pigs) to 11.3 (chicken) mg B/L (ANZECC, 2000). These guidelines were calculated as follows:

E.g. Cattle (150 kg):

$$\text{Guideline} = \frac{\text{MTDL} * \text{daily feed intake} * \text{B contribution from water}}{\text{Maximum daily water intake} * \text{safety factor}} = \frac{150\text{mg/kg/d} * 20\text{kg} * 0.2}{85\text{ L/d}} = 7\text{mg/L}$$

Where:

- MTDL = the suggested maximum total dietary level of 150 mg/kg boron in the animal diet;
- 20 kg/d is an estimate of the average food consumption of cattle assuming they consume about 2.5% of their bodyweight in feed;
- 0.2 is the proportion of boron attributed to the intake of water;
- 85 L/d is the peak consumption rate of water for cattle

A safety factor for possible long-term effects was not included in the calculations because it was considered unlikely of any long-term effects due to boron ingestion. Although the calculated value for cattle is above the recommended guideline, other livestock, such as pigs, may be more sensitive to boron in the diet. Please see Table 6 for a summary of the calculations.

Table 6. Summary of calculations used to develop a guideline for boron in livestock drinking water. (ANZECC, 2000)

Animal	Body Weight (kg)	Peak water intake (L/d)	Peak food intake (kg/d)	Calculated value (mg/L)
Cattle	150	85	20	7
Pigs	110	15	2.9	5.8
Sheep	100	11.5	2.4	6.2
Chickens/ Poultry	2.8	0.4	0.15	11.3
Horses	600	70	20	8.6

Other jurisdictions such as the US Environmental Protection Agency also suggest a livestock watering guideline for boron to be 5.0 mg/L (EPA, 1988). This level provides a safety factor of 8:1 to the effects studies of Green and Weeth, who found the safe tolerance of boron between 40 and 150 mg/L.

It should be kept in mind that, in general, normal drinking water has less than 1.0 mg/L boron and it is unlikely that livestock will be exposed to high levels of boron in their drinking water.

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Figure 1. Boron Toxicity to Freshwater Vertebrates

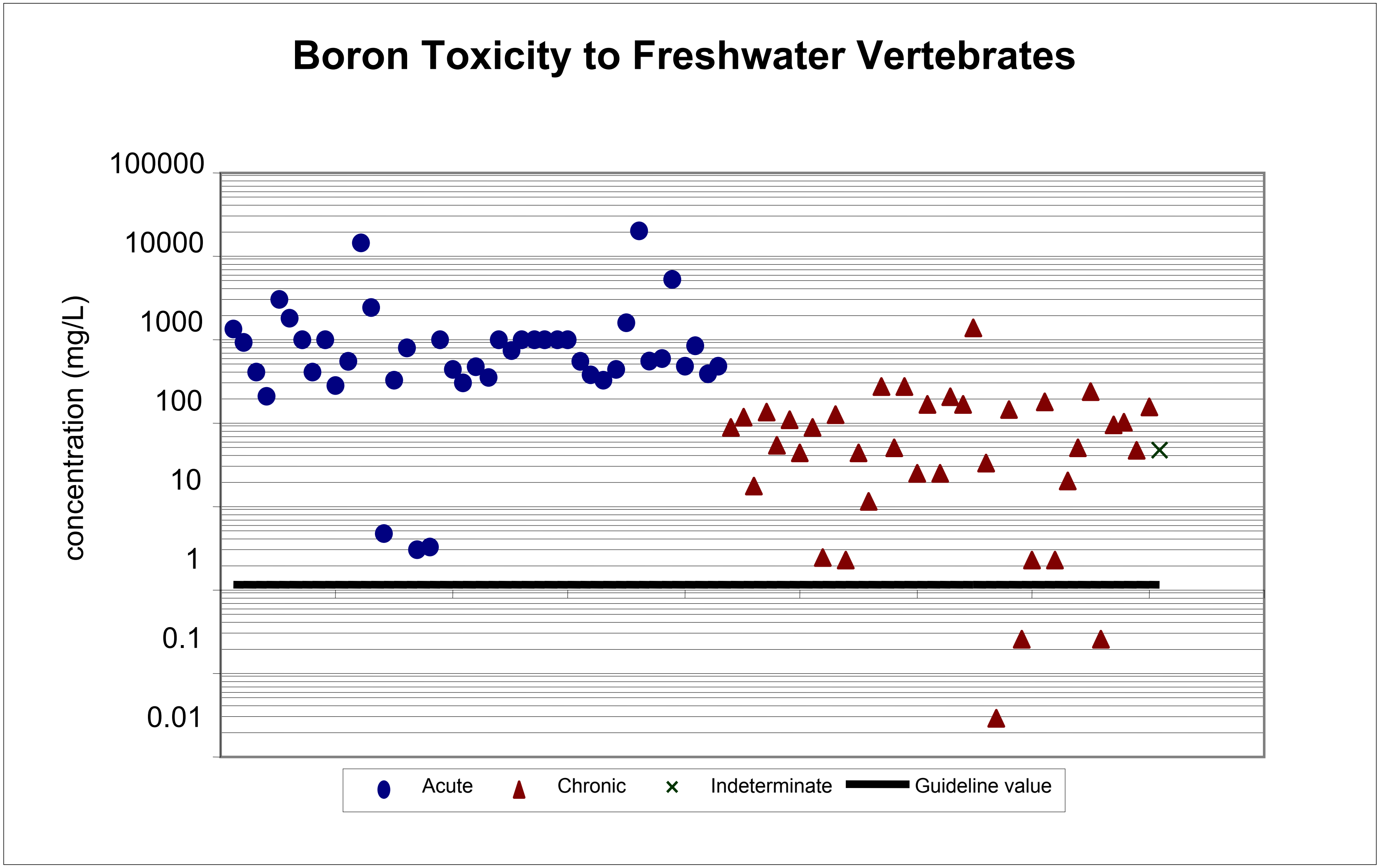

Figure 2. Boron Toxicity to Freshwater Invertebrates

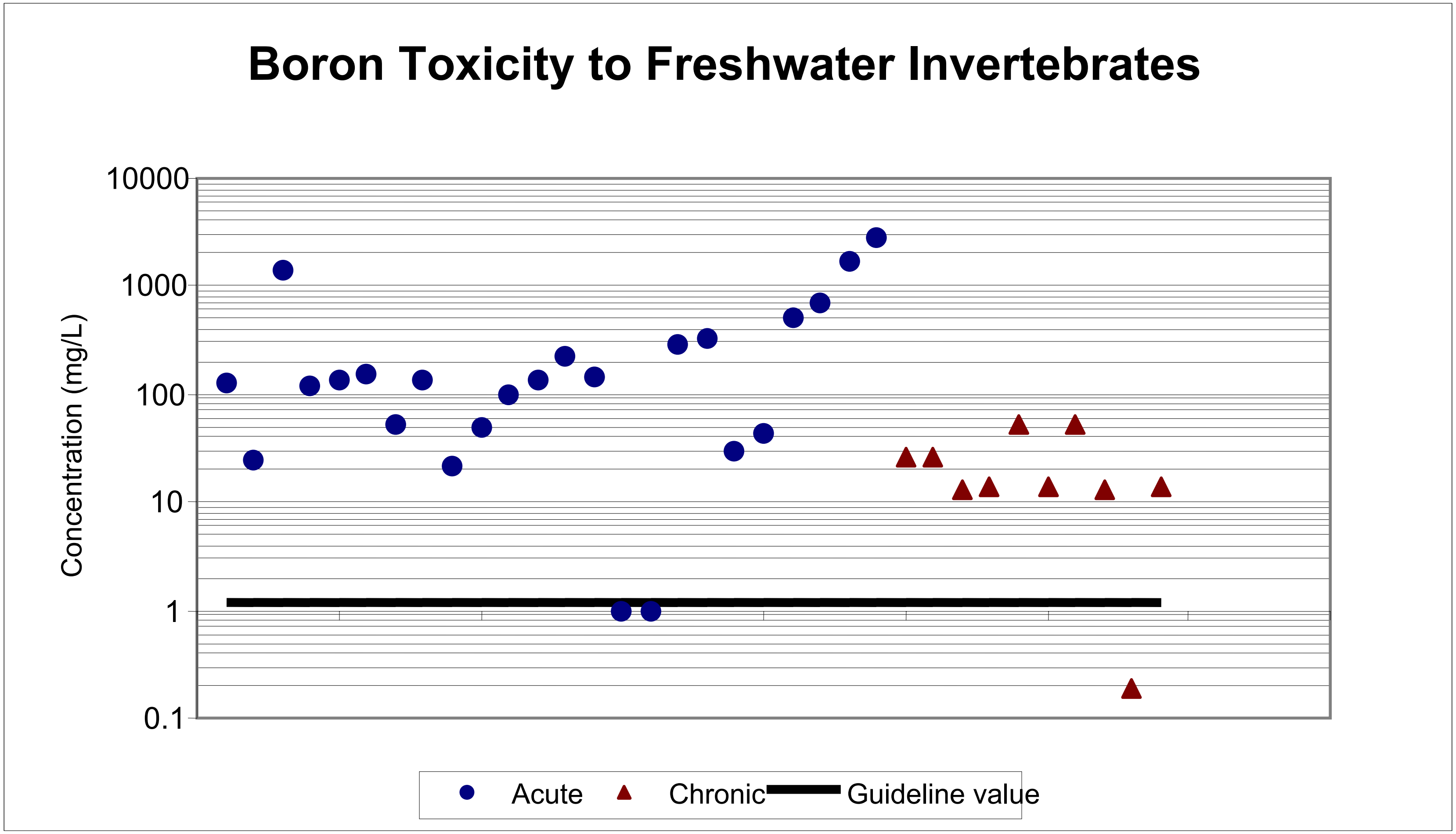

Figure 3. Boron Toxicity to Freshwater Plants

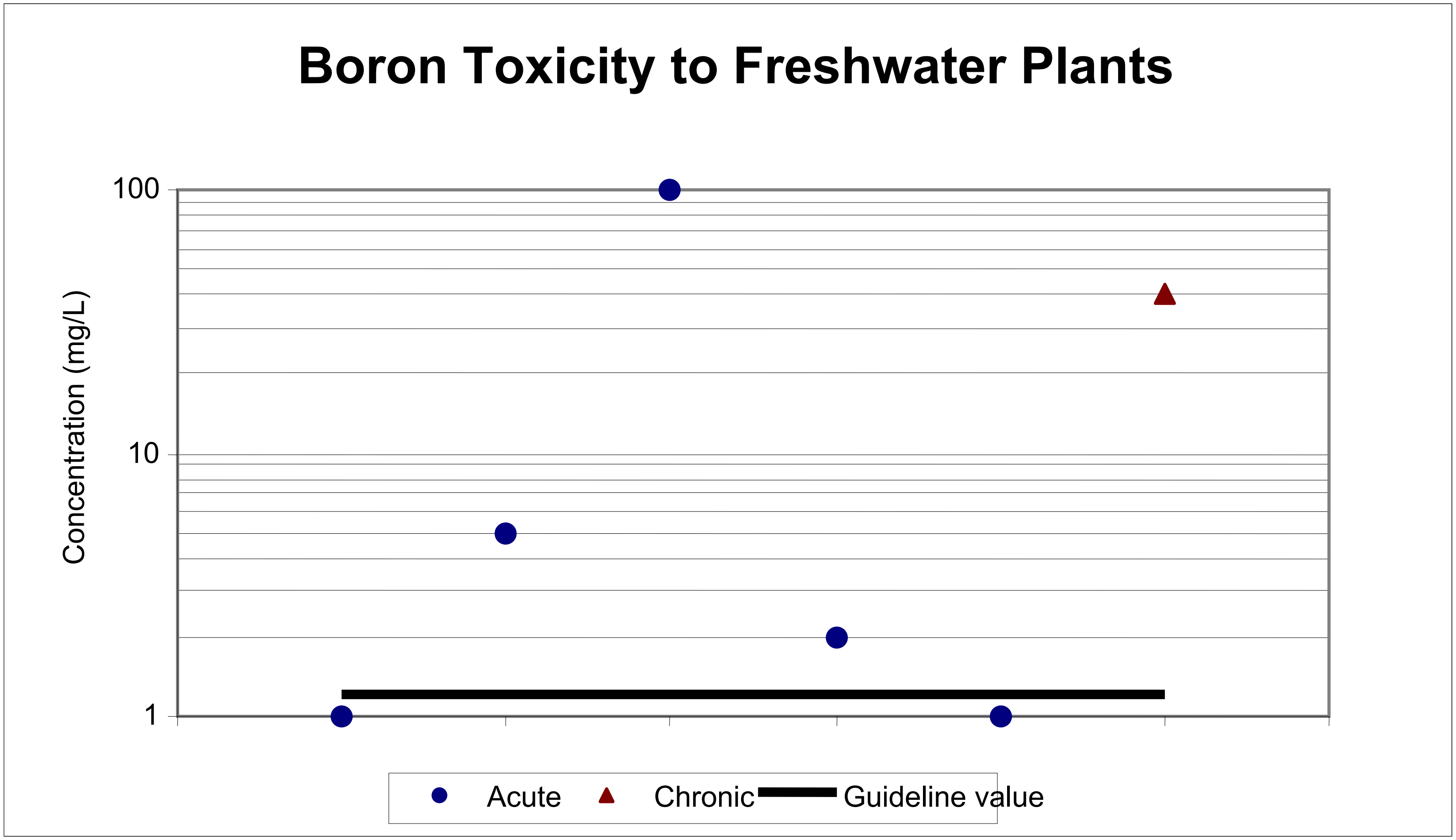

Figure 4. Boron Toxicity to Freshwater Algae

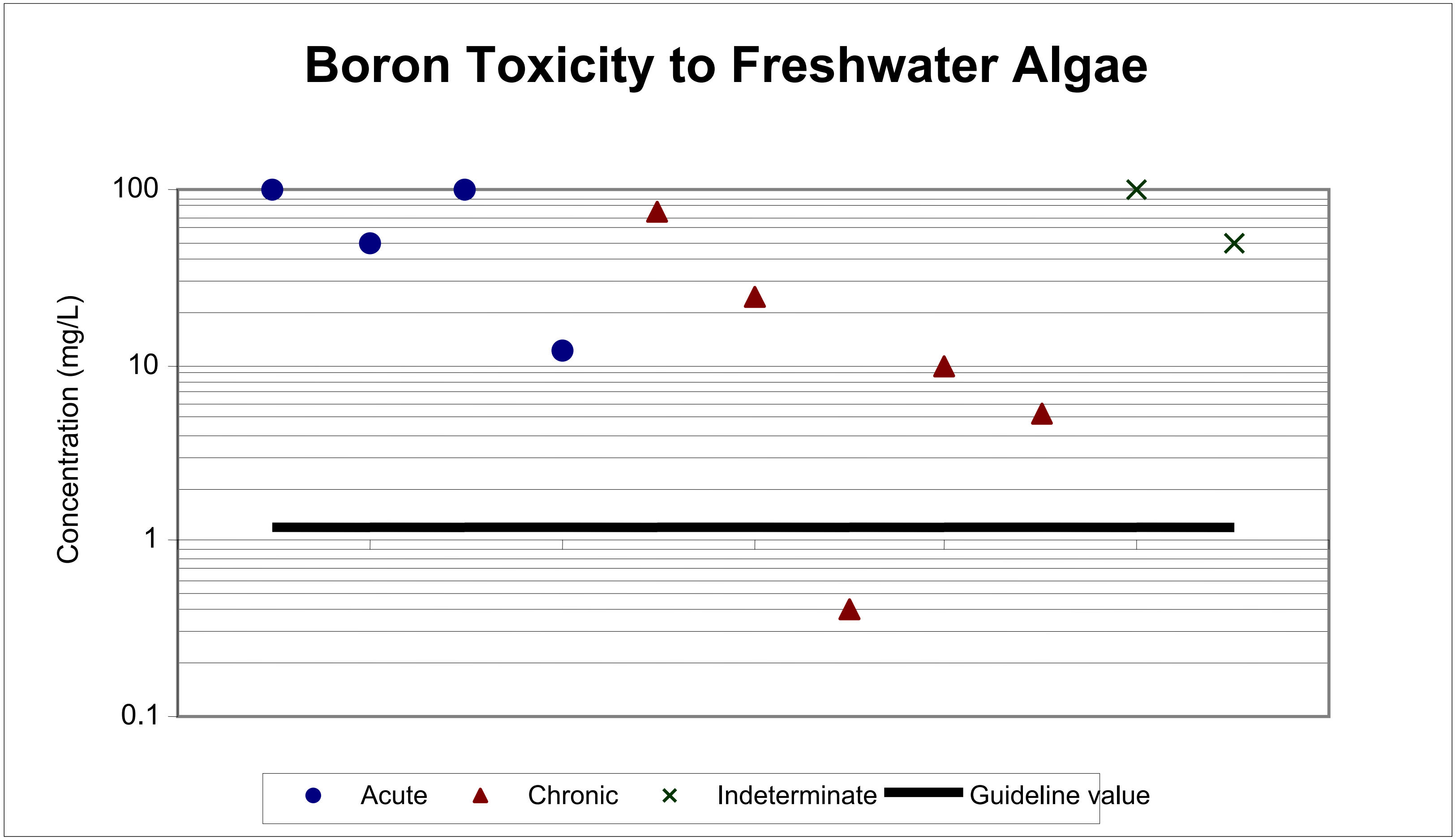

Figure 5. Boron Toxicity to Freshwater Amphibians

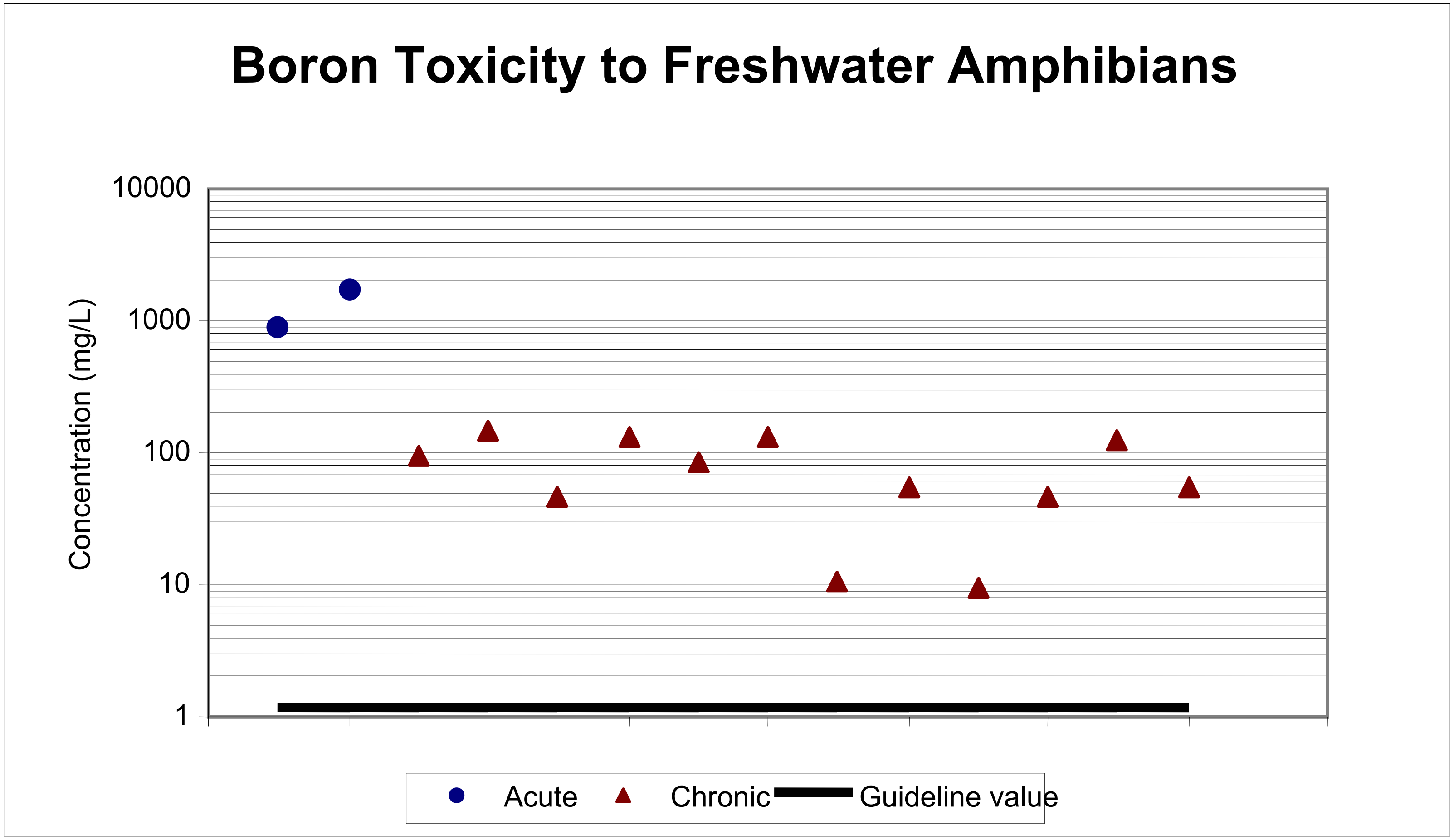

Figure 6. Boron Toxicity to Marine Vertebrates

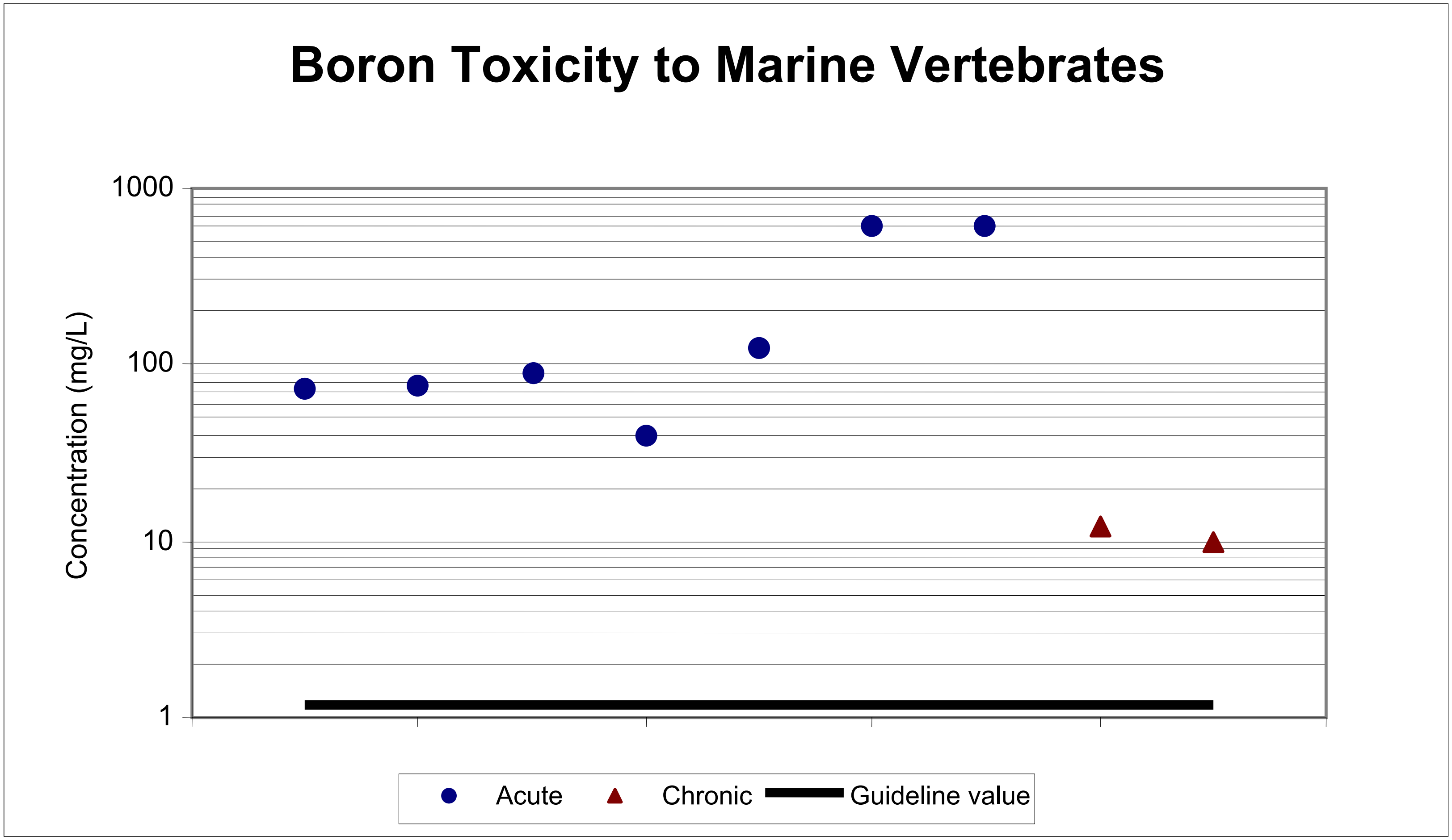

Figure 7. Boron Toxicity to Marine Invertebrates

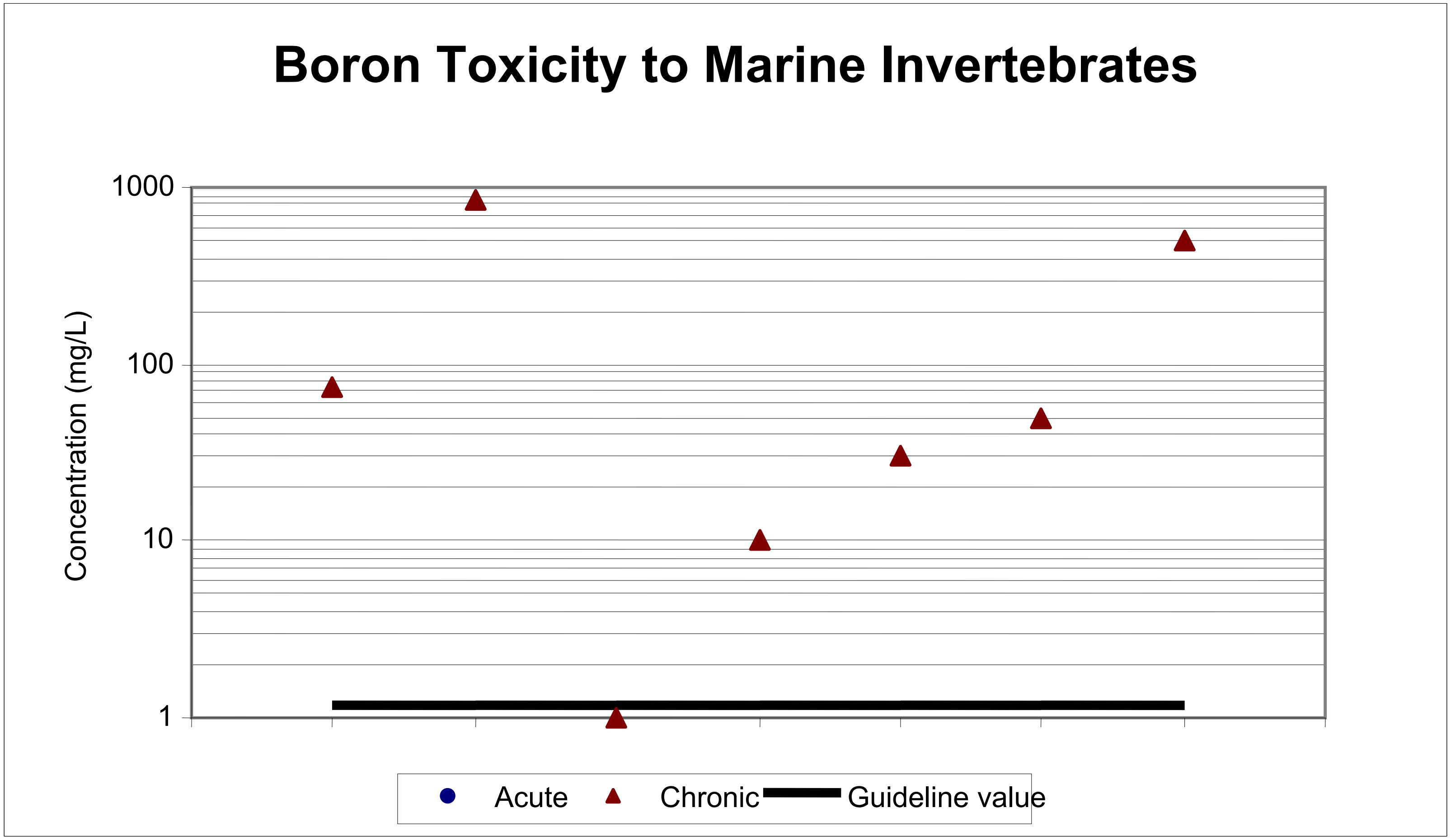

Table 7. Effects of Boron on Freshwater Aquatic Life

Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp (°C)	Alkalinity (mg/L)	Hardness (mg/L)	Concentration (mg B/L)	Effect	Reference	Chronic, Acute or Indeterminate Study?
Algae and Bacteria													
Anacystis nidulans (blue green algae)			boric acid							0.01-4.0	grows well in B-deficient media; growth neither stimulated nor inhibited at higher levels	Martinez et al (1986b) and Mateo et al (1987) *in Eisler (1990)*	C
Anacystis nidulans (blue green algae)			boric acid							50	no effect on growth or organic constituents	Martinez et al (1986a) *in Eisler (1990)*	C
Anacystis nidulans (blue green algae)			boric acid							100	decrease in protein content causing inhibition in nitrate uptake and nitrate reductase activity. Decreased chlorophyll content and photo-synthesis inhibition within 72h.	Martinez et al (1986a) and Mateo et al (1987) *in Eisler (1990)*	A

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Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp (^{o}C)	Alkalinity (mg/L)	Hardness (mg/L)	Concentration (mg B/L)	Effect	Reference	Chronic, Acute or Indeterminate Study?
Anacystis nidulans (cyanobacteria)			boric acid							75	Significantly decreased growth and chlorophyll content	Martinez et al (1986a) *in Maier and Knight (1991)*	C
Chlorella pyrenoidosa (green alga)			boron							≥ 25	Decreased algal growth; Increase in protein & nucleic acid synthesis	Sanchez et al (1982) *in Maier and Knight (1991)*	C
Chlorella pyrenoidosa (green alga)										50-100	Altered cell division and amino acid activity after 72h; reversible photosyn inhibition; Giant cells formed with increased nitrate and protein.	Maeso et al (1985) *in Eisler (1990)*	A
Chlorella pyrenoidosa (green alga)										>100	Totally inhibitory for cell division and biomass synthesis in 72h	Maeso et al (1985) *in Eisler (1990)*	A

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Chlorella pyrenoidosa (green alga)										0.4	14d NOEC, population growth	Australia and New Zealand Environment and Conservation Council (1999)	C
Chlorella pyrenoidosa (green alga)										10	no effect on growth or cell composition; bio-concentration factor (BCF) of x4 after 7 days	Fernandez et al (1984) *in Eisler (1990)*	C
Chlorella pyrenoidosa (green alga)										50	BCF of x5 after 7 days	Fernandez et al (1984) *in Eisler (1990)*	C
Chlorella pyrenoidosa (green alga)										100	BCF of x4.8 after 7 days	Fernandez et al (1984) *in Eisler (1990)*	C
Chlorella. protothicoides and *C. emersanii* (Chlorella algae)										100	Toxic	Bowen and Gauch (1966) *in Butterwick, L. et al (1989)*	I

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Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp (°C)	Alkalinity (mg/L)	Hardness (mg/L)	Concentration (mg B/L)	Effect	Reference	Chronic, Acute or Indeterminate Study?
Chlorella. vulgaris (Chlorella algae)										50	Toxic	Bowen and Gauch (1966) *in Butterwick, L. et al (1989)*	I
Chlorella. vulgaris (Chlorella algae)										5.2	NOEC, population growth	Australia and New Zealand Environment and Conservation Council (1999)	C
Selenastrum capricornutum	4-7d old	72h static		reconstituted			24 +/- 2			<12.3 12.3	NOEC LOEC	MELP (unpubl)	A
Amphibians													
Bufo fowleri (Fowler's toad)	embryo-larval stages	Flow-through	boric acid	reconstituted	7.6	6.8	23.7	82	200	22.3-53.5 5 123	7 day NOEC-LOEC LC_1 (7d.) LC_{50} (7d)	Birge and Black (1977) *in Butterwick, L. et al (1989) and Eisler (1990)*	C

Table 7. Effects of Boron on Freshwater Aquatic Life

Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp (^{o}C)	Alkalinity (mg/L)	Hardness (mg/L)	Concentration (mg B/L)	Effect	Reference	Chronic, Acute or Indeterminate Study?
Bufo fowleri (Fowler's toad)	embryo-larval stages	Flow-through	boric acid	reconstituted	7.6	6.8	23.7		50	48.7-96.0 25 145	7 day NOEC-LOEC LC$_1$ (7.5d.) LC$_{50}$ (7.5d)	Birge and Black (1977) *in Butterwick, L. et al (1989) and Eisler (1990)*	C
Bufo vulgaris (Toad)	embryo	24h exposure from 2 cell stage to tailbud stage	boric acid							874	malformation included edema, micro-cephalia, short tail, and suppressed forebrain development	EPA (1975) *in Eisler (1990)*	A
Bufo vulgaris formosus (Toad)	embryo	Static; embryos exposed to B for 24 hr at various embryonic stages and then cultured in tap water until 14 days past fertilisatn	boric acid	tap						1747 (1% soln)	teratogenic defects and reduced survival	Takeuchi (1958) *in Butterwick, L. et al (1989)*	A

Table 7. Effects of Boron on Freshwater Aquatic Life

Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp (^{o}C)	Alkalinity (mg/L)	Hardness (mg/L)	Concentration (mg B/L)	Effect	Reference	Chronic, Acute or Indeterminate Study?
Rana pipiens (Leopard frog)	embryo-larval stages	Flow-through	boric acid	reconstituted	7.7	7.7	25.0		50	32.5-47.5 13 130	7 day NOEC-LOEC LC$_1$ (7.5d) LC$_{50}$(7.5d)	Birge and Black (1977) *in Butterwick, L. et al (1989) and Eisler (1990)*	C
Rana pipiens (Leopard frog)	embryo-larval stages	Flow-through	boric acid	reconstituted	7.7	7.8	25.0	82	200	45.7-86.0 22 135	7 day NOEC-LOEC LC$_1$ (7.5d) LC$_{50}$(7.5d)	Birge and Black (1977) *in Butterwick, L. et al (1989) and Eisler (2990)*	C
Rana pipiens (Leopard frog)	embryo-larval stages	Flow-through	borax	reconstituted	8.4	7.8	25.3	82	200	7.04-10.5 3 54	7 day NOEC-LOEC LC$_1$ (7.5d) LC$_{50}$(7.5d)	Birge and Black (1977) *in Butterwick, L. et al (1989) and Eisler (1990)*	C

Table 7. Effects of Boron on Freshwater Aquatic Life

Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp (°C)	Alkalinity (mg/L)	Hardness (mg/L)	Concentration (mg B/L)	Effect	Reference	Chronic, Acute or Indeterminate Study?
Rana pipiens (Leopard frog)	embryo-larval stages	Flow-through	borax	reconstituted	8.3	7.7	25.3		50	7.04-9.6 5 47	7 day NOEC-LOEC LC_1 (7.5d) LC_{50}(7.5d)	Birge and Black (1977) *in Butterwick, L. et al (1989) and Eisler (1990)*	C
Invertebrates													
Anopheles quadrimaculatus (Mosquito larvae)			boric acid							125 25	100% mortality after 25 hr 92% mortality after 48hr	Fay (1959) *in Butterwick, L. et al (1989)*	A
Chironomus decorus (Midge)	fourth instar	48 hr acute toxicity	sodium tetraborate	reconstituted	9.1	8.6	20		10.6-170	1376	48 hr LC_{50} no significant interaction between water hardness and boron; in experimts with sulfate, sulfate did not signifcantly affect the mortality assoc. with boron exposure.	Maier and Knight (1991)	A

Table 7. Effects of Boron on Freshwater Aquatic Life

Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp (^{o}C)	Alkalinity (mg/L)	Hardness (mg/L)	Concentration (mg B/L)	Effect	Reference	Chronic, Acute or Indeterminate Study?
Chironomus tentans (Midge)	third instar larval	acute	boric acid	reconstituted			23 +/- 1		100	118	96h-LC_{50}	MELP (unpubl)	A
									250	137.7	96h-LC_{50}		
									25	157.3	96h-LC_{50}		
Daphia magna	neonates	acute lethality	boric acid	well, reconstituted			20 +/- 2		100	52.4	48h-LC_{50}	MELP (unpubl)	A
									250	139.2	48h-LC_{50}		
									25	21.3	48h-LC_{50}		
Daphia magna	all tests start with daphnia <24h old	chronic - static	boric acid	well, reconstituted					100	50	Acute lethal LOEC	MELP (unpubl)	A & C
										25.6	Acute NOEC		
										25.4	Chronic LOEC		
										13.1	Chronic NOEC		
									250	100	Acute lethal LOEC		
										50	Acute NOEC		
										26.4	Chronic LOEC		
										12.4	Chronic NOEC		

Table 7. Effects of Boron on Freshwater Aquatic Life

Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp (^{o}C)	Alkalinity (mg/L)	Hardness (mg/L)	Concentration (mg B/L)	Effect	Reference	Chronic, Acute or Indeterminate Study?
Daphia magna										4.665 ~9.3 ~266 6.0	NOEC equivalent, growth 21d MATC, growth 21d LC_{50} NOEC, reproduction	Australia and New Zealand Environment and Conservation Council (1999)	C
Daphia magna Straus			boric acid							13	Significantly smaller brood sizes	Lewis & Valentine (1981). *in Maier and Knight (1991)*	C
Daphia magna Straus		Static	boric acid							14	decrease in growth, mean number of broods per daphnid, man total number of young per daphnid and mean brood size per daphnid	Gersich (1984) *in Maier and Knight (1991)*	C

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Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp (^{o}C)	Alkalinity (mg/L)	Hardness (mg/L)	Concentration (mg B/L)	Effect	Reference	Chronic, Acute or Indeterminate Study?
Daphia magna Straus		Static	boric acid	Lake Huron	6.7-8.1		20		150	133	48 hr LC_{50}	Gersich (1984) *in Maier and Knight (1991)*	A
Daphia magna Straus	< 24 hr	48 hr static acute	boric acid	Carbon filtered	7.1-8.7	9 mg/L	19.2		166	226	48 hr LC_{50}	Lewis & Valentine (1981). *in Maier and Knight (1991)*	A
Daphia magna Straus		Static renewal (3 times wkly)	boric acid	Lake Huron	7.3-8.0		20		150	52.2 6.4-13.6	21 day LC_{50} 21 day NOEC-LOEC	Gersich (1984) *in Butterwick, L. et al (1989)*	C
Daphia magna Straus	<24 hr	21 day static renewal chronic	boric acid	Carbon filtered	7.1-8.7	9 mg/L	19.2		166	53.2 6-13	21 day LC_{50} 21 day NOEC-LOEC	Lewis & Valentine (1981). Also *in Butterwick, L. et al (1989)*	C
Daphnia magna			Sodium perborate	Lake Erie			25			<0.38 estimated to be 0.19	threshold concen-tration for immobilisation	McKee and Wolf (1963) *in Butterwick, L. et al (1989)*	C

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Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp (°C)	Alkalinity (mg/L)	Hardness (mg/L)	Concentration (mg B/L)	Effect	Reference	Chronic, Acute or Indeterminate Study?
Daphnia magna			Sodium tetraborate							<27.2 estimated to be 13.6	threshold concen-tration for immobilisation	McKee and Wolf (1963) *in Butterwick, L. et al (1989)*	C
Daphnia magna	neonate	48 hr acute toxicity	sodium tetraborate	reconstituted	9.1	8.6	20		10.6-170	141	48 hr LC_{50} no significant interaction between water hardness and boron; in experiments with sulfate, sulfate did not significantly affect the mortality assoc. with boron exposure.	Maier and Knight (1991)	A
Dugesia dorotocephala		1hr behavioural test	boron		6.0-8.0				370	1.0 10.0	restlessness, hyperkinesia, spiralling and head/nose twist within 5 min. exposure	Kapu & Schaeffer (1991)	A

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Entosiphon sulcatum (Protozoan)		Static	Sodium tetraborate	Culture medium	adjusted to 6.9		25			1.0	Toxicity threshold (measured as a 5% reduction in cell replication after 72hr)	Bringmann (1978) *in Butterwick, L. et al (1989)*	A
Hyalella azteca		acute	boric acid	reconstituted			23 +/- 1		100 250 25	291.3 333.6 28.9	96h-LC_{50} 96h-LC_{50} 96h-LC_{50}	MELP (unpubl)	A
Mosquito larvae, 3 species	larvae		boric acid							43.7 524 700 1,748 2,797	LC_{97}-LC_{99} through hatching LC_{100} (48h), second instar LC_{100} (48h), freshly hatched LC_{100} (48hr), third instar LC_{100} (48hr), pupae	EPA (1975) *in Eisler (1990)*	A

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Vertebrates													
Carassius auratus (Goldfish)	embryo larval stages	Flow-through	borax	reconstituted	8.3	7.5	27.0		50	26.50-48.75 1.4 65	7 day NOEC-LOEC LC$_1$ (7d) LC$_{50}$ (7d)	Birge and Black (1977) *in Butterwick, L. et al (1989) and Eisler (1990)*	C
Carassius auratus (Goldfish)	embryo larval stages	Flow-through	boric acid	reconstituted	7.6	7.5	24.8	82	200	6.8-8.33 0.2 75	7 day NOEC-LOEC LC$_1$ (7d) LC$_{50}$ (7d)	Birge and Black (1977) *in Butterwick, L. et al (1989) and Eisler (1990)*	C
Carassius auratus (Goldfish)	embryo larval stages	Flow-through	borax	reconstituted	8.1	7.5	27.0	82	200	8.53-27.33 0.9 59	7 day NOEC-LOEC LC$_1$ (7d) LC$_{50}$ (7d)	Birge and Black (1977) *in Butterwick, L. et al (1989) and Eisler (1990)*	C

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Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp (^{o}C)	Alkalinity (mg/L)	Hardness (mg/L)	Concentration (mg B/L)	Effect	Reference	Chronic, Acute or Indeterminate Study?
Carassius auratus (Goldfish)	embryo larval stages	Flow-through	boric acid	reconstituted	7.9	7.4	24.8		50	9.2-22.5 0.6 46	7 day NOEC-LOEC LC$_1$ (7d) LC$_{50}$ (7d)	Birge and Black (1977) *in Butterwick, L. et al (1989) and Eisler (1990)*	C
Gambusia afinis (Mosquito fish*)*	adult females	Static	Sodium tetraborate		8.6-9.1		22-26			1360 929 408 215 <204	24 hr TLm 48 hr TLm 96 hr TLm 144 hr TLm No mortalities	Wallen et al. (1957) *in Butterwick, L. et al (1989)*	A
Gambusia afinis (Mosquito fish*)*	adult females	Static	boric acid		5.4-7.3		20-23			3145 1834 978 <314	24 hr TLm 48 hr TLm 96 hr TLm no mortalities in 96hr	Wallen et al. (1957) *in Butterwick, L. et al (1989)*	A
Gambusia afinis (Mosquito fish*)*	adults		sodium borate							3600 sodium borate (396 mg B/L)	96hr LC$_{50}$	Birge and Black (1977) *in Eisler (1990)*	A

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Gambusia afinis (Mosquito fish)	adults		boric acid							979	96hr LC$_{50}$	Birge and Black (1977) *in Eisler (1990)*	A
Gila elegans (Bonytail)	swimup fry	static acute toxicity test	boric acid	reconstituted	7.0-8.5		25	107	196	280	96 hr LC$_{50}$	Hamilton, S.J. (1995)	A
Gila elegans (Bonytail)	2.6g juvenile	static acute toxicity test	boric acid	reconstituted	7.0-8.5		25	107	196	552	96 hr LC$_{50}$	Hamilton, S.J. (1995)	A
Ictalurus punctatus (Channel catfish)	embryo larval stages	Flow-through	borax	reconstituted	8.2	6.5	29.4	82	200	0.49-1.04 1.7 71	9 day NOEC-LOEC LC$_{1}$ (9d) LC$_{50}$ (9d)	Birge and Black (1977) *in Butterwick, L. et al (1989) and Eisler (1990)*	C
Ictalurus punctatus (Channel catfish)	embryo larval stages	Flow-through	boric acid	reconstituted	7.6	7.6	24.7	82	200	0.75-1.0 0.2 22	9 day NOEC-LOEC LC$_{1}$ (9d) LC$_{50}$ (9d)	Birge and Black (1977) *in Butterwick, L. et al (1989) and Eisler (1990)*	C

Table 7. Effects of Boron on Freshwater Aquatic Life

Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp (°C)	Alkalinity (mg/L)	Hardness (mg/L)	Concentration (mg B/L)	Effect	Reference	Chronic, Acute or Indeterminate Study?
Ictalurus punctatus (Channel catfish)	embryo larval stages	Flow-through	boric acid	reconstituted	7.5	7.3	25.0		50	1.01-5.42 0.5 155	9 day NOEC-LOEC LC$_1$ (9d) LC$_{50}$ (9d)	Birge and Black (1977) *in Butterwick, L. et al (1989) and Eisler (1990)*	C
Ictalurus punctatus (Channel catfish)	embryo larval stages	Flow-through	borax	reconstituted	8.5	6.4	29.4		50	9.0-25.9 5.5 155	9 day NOEC-LOEC LC$_1$ (9d) LC$_{50}$ (9d)	Birge and Black (1977) *in Butterwick, L. et al (1989) and Eisler (1990)*	C
Lepomis macrochirus (Bluegill)			boron trifluoride							15,000	LC$_{50}$ (24h)	Birge and Black (1977) *in Eisler (1990)*	A
Lepomis macrochirus (Bluegill sunfish)	av size 7cm, 5g	static	boron trifluoride	tap			20	1750		2389	24 hr TLm	Turnbull et al. (1954) *in Butterwick, L. et al (1989)*	A

Table 7. Effects of Boron on Freshwater Aquatic Life

Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp (^{0}C)	Alkalinity (mg/L)	Hardness (mg/L)	Concentration (mg B/L)	Effect	Reference	Chronic, Acute or Indeterminate Study?
Lepomis macrochirus (Bluegill sunfish)	av.size 7cm, 5g	static	Sodium tetraborate	tap	6.9-7.5		20	33-81	84-163	4.6	24 hr TLm	Turnbull et al. (1954) *in Butterwick, L. et al (1989)*	A
Micropterus salmoides (Largemouth bass)	embryo-larval stages	Flow-through	boron	reconstituted	7.5	8.4	20		204	1.39	NOEC	Black, Barnum & Birge (1993)	C
										12.17	LOEC		
										92	8 day LC_{50}		
Micropterus salmoides (Largemouth bass)	freshly fertilised eggs	Flow-through	boric acid	reconstituted					200	1.39-12.17	11 day NOEC-LOEC	Birge and Black (1981) *in Butterwick, L. et al (1989)*	C
Minnow			Sodium tetraborate	distil-led			19			340-374	minimum lethal dose	McKee and Wolf (1963) *in Butterwick, L. et al (1989)*	A
				hard			17			793-850	minimum lethal dose		
Minnow			boric acid	distil-led			20			3.145-3.319	6hr minimum lethal dose	NAS (1973), McKee and Wolf (1963) *in Butterwick, L. et al (1989)*	A
				hard			20			3.319-3.407	6hr minimum lethal dose		

Table 7. Effects of Boron on Freshwater Aquatic Life

Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp (°C)	Alkalinity (mg/L)	Hardness (mg/L)	Concentration (mg B/L)	Effect	Reference	Chronic, Acute or Indeterminate Study?
Oncorhynchus kisutch (Coho salmon)	swim up fry (0.5 g mean weight)	static acute toxicity	boric acid	reconstituted fresh	7.82		12		211	>1000 447	24hr LC_{50} 96hr LC_{50}	Hamilton, S.J. and K.J. Buhl. (1990)	A
Oncorhynchus kisutch (Coho salmon)	salmonids	acute lethality	boric acid	well, artificial hard, artificial soft			15 +/- 1		100 250 25	304.1 477.1 357.4	96h-LC_{50} 96h-LC_{50} 96h-LC_{50}	MELP (unpubl)	A
Oncorhynchus kisutch (Coho salmon)	alevins 0.19-0.7 g	static renewal (daily)	Sodium metaborate	well			11		47	113	283 hr LC_{50}	Thompson et al (1976) *in Butterwick, L. et al (1989) and Eisler (2990)*	C
Oncorhynchus kisutch (Coho salmon)	alevins and fry	static renewal (daily)	Sodium metaborate	soft	7		11			93	23 day LC_{50}	Davis, J.C. et. al (1973)	C
Oncorhynchus tshawytscha (Chinook salmon)	swim up fry (1.1g mean weight)	static acute toxicity	boric acid	reconstituted fresh	7.82		12		211	>1000 725	24hr LC_{50} 96hr LC_{50}	Hamilton, S.J. and K.J. Buhl. (1990)	A
Oncorhynchus tshawytscha (Chinook salmon)	eyed egg	static acute toxicity	boric acid	reconstituted soft	7.57		12		41.7	>1000 >1000	24hr LC_{50} 96hr LC_{50}	Hamilton, S.J. and K.J. Buhl. (1990)	A

Table 7. Effects of Boron on Freshwater Aquatic Life

Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp (°C)	Alkalinity (mg/L)	Hardness (mg/L)	Concentration (mg B/L)	Effect	Reference	Chronic, Acute or Indeterminate Study?
Oncorhynchus tshawytscha (Chinook salmon)	alevin	static acute toxicity	boric acid	reconstituted soft	7.57		12		41.7	>1000 >1000	24hr LC$_{50}$ 96hr LC$_{50}$	Hamilton, S.J. and K.J. Buhl. (1990)	A
Oncorhynchus tshawytscha (Chinook salmon)	0.31g	static acute toxicity	boric acid	reconstituted soft	7.57		12		41.7	>1000 566	24hr LC$_{50}$ 96hr LC$_{50}$	Hamilton, S.J. and K.J. Buhl. (1990)	A
Oncorhyncus mykiss (Rainbow trout)	early life stages	acute	boric acid	well, artificial hard, artificial soft			15.0 +/- 1.0		100 250 25	379.6 336 436.2	96 hr LC$_{50}$ 96 hr LC$_{50}$ 96 hr LC$_{50}$	MELP (unpubl)	A
Oncorhyncus mykiss (Rainbow trout)	early life stages	7d embryo test - static renewal (80% every 24h)		hard						969	7d-EC$_{50}$	MELP (unpubl)	A
Oncorhyncus mykiss (Rainbow trout)		Screened chronic								0.04 ~0.1 ~138	NOEC equivalent, mortality 32d LOEC, mortality 32d LC$_{50}$	Australia and New Zealand Environment and Conservation Council (1999)	C

Table 7. Effects of Boron on Freshwater Aquatic Life

Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp (^oC)	Alkalinity (mg/L)	Hardness (mg/L)	Concentration (mg B/L)	Effect	Reference	Chronic, Acute or Indeterminate Study?
Oncorhyncus mykiss (Salmo gairdneri) (Rainbow trout)			boric acid							874	Darkening of skin, immobilisation and loss of equilibrium	Wurtz (1945) *in Butterwick, L. et al (1989)*	C
Oncorhyncus mykiss (Salmo gairdneri) (Rainbow trout)	adults									14000	After exposure for 30min, all recovered if placed in flowing B-free water	Sprague (1972) *in Eisler (1990)*	A
Oncorhyncus mykiss (Salmo gairdneri) (Rainbow trout)	adults									339	LC_{50} (48h)	Lewis and Valentine (1981), Birge and Black (1977), Sprague (1972) *in Eisler (1990)*	A
Oncorhyncus mykiss (Salmo gairdneri) (Rainbow trout)	adults									350	No effect after 30min	Sprague (1972) *in Eisler (1990)*	A

Table 7. Effects of Boron on Freshwater Aquatic Life

Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp (^{o}C)	Alkalinity (mg/L)	Hardness (mg/L)	Concentration (mg B/L)	Effect	Reference	Chronic, Acute or Indeterminate Study?
Oncorhyncus mykiss (Salmo gairdneri) (Rainbow trout)	adults									3500	All alive after 30min, but in obvious distress	Sprague (1972) *in Eisler (1990)*	A
Oncorhyncus mykiss (Salmo gairdneri) (Rainbow trout)	early life stages	Flow-through	boric acid	well	6.5-7.5				27	>17	60 day LOEC	Procter & Gamble (unpub) *in Butterwick, L. et al (1989)*	C
Oncorhyncus mykiss (Salmo gairdneri) (Rainbow trout)	embryo larval stages	Flow-through	boric acid	reconstituted	7.9	9.6	13.3	82	200	0.001-0.01 0.001 79	28 day NOEC-LOEC LC_1 (28d) LC_{50}(28d)	Birge and Black (1977) *in Butterwick, L. et al (1989) and Eisler (1990)*	C
Oncorhyncus mykiss (Salmo gairdneri) (Rainbow trout)	freshly fertilised eggs	Flow-through	boric acid	reconstituted					200	0.01-0.1	32 day NOEC-LOEC	Birge and Black (1981) *in Butterwick, L. et al (1989)*	C

Table 7. Effects of Boron on Freshwater Aquatic Life

Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp (^{o}C)	Alkalinity (mg/L)	Hardness (mg/L)	Concentration (mg B/L)	Effect	Reference	Chronic, Acute or Indeterminate Study?
Oncorhyncus mykiss (Salmo gairdneri) (Rainbow trout)	embryo larval stages	Flow-through	boric acid	reconstituted	7.7	9.2	13.7		50	0.11-1.00 0.1 100	28 day NOEC-LOEC LC$_1$ (28d) LC$_{50}$(28d)	Birge and Black (1977) *in Butterwick, L. et al (1989) and Eisler (1990)*	C
Oncorhyncus mykiss (Salmo gairdneri) (Rainbow trout)	early life stages	Flow-through	boric acid	natural water exposures						0.75-1.0	36 day NOEC-LOEC	Procter & Gamble (unpub) *in Butterwick, L. et al (1989)*	C
Oncorhyncus mykiss (Salmo gairdneri) (Rainbow trout)	embryo larval stages	Flow-through	borax	reconstituted	7.9	10.1	14.0		50	0.96-9.70 0.07 27	28 day NOEC-LOEC LC$_1$ (28d) LC$_{50}$(28d)	Birge and Black (1977) *in Butterwick, L. et al (1989) and Eisler (1990)*	C
Oncorhyncus mykiss (Salmo gairdneri) (Rainbow trout)	embryo	Flow-through	boric acid	reconstituted	7.4	9.8	13.2		197	138 0.10	8 day LC$_{50}$ LOEC	Black, Barnum & Birge (1993)	C

Table 7. Effects of Boron on Freshwater Aquatic Life

Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp (^{o}C)	Alkalinity (mg/L)	Hardness (mg/L)	Concentration (mg B/L)	Effect	Reference	Chronic, Acute or Indeterminate Study?
Oncorhyncus mykiss (Salmo gairdneri) (Rainbow trout)	embryo larval stages	Flow-through	borax	reconstituted	7.8	10.3	13.0	82	200	9.63-49.70 0.07 54	28 day NOEC-LOEC LC$_1$ (28d) LC$_{50}$(28d)	Birge and Black (1977) *in Butterwick, L. et al (1989) and Eisler (1990)*	C
Oncorhyncus mykiss (Salmo gairdneri) (Rainbow trout)	embryo	continuous flow	boric acid	natural - from well	6.8-7.1		12	25-38	90-150	18	20 day NOEC	Black, Barnum & Birge (1993)	C
Pimeohales promelas (Fathead minnow)	eggs and fry	Flow-through early lifestage	boric acid	well	7.1-7.9		25	33-38	38-46	14-24 24-88	30 day NOEC-LOEC (reduction in growth) 60 day NOEC-LOEC (reduction in fry survival)	Procter & Gamble (1979) (unpub) *in Butterwick, L. et al (1989)*	C
Ptychocheilus lucius (Colorado squawfish)	swimup fry	static acute toxicity test	boric acid	reconstituted	7.0-8.5		25	107	196	279	96 hr LC$_{50}$	Hamilton, S.J. (1995)	A
Ptychocheilus lucius (Colorado squawfish)	1.7g juvenile	static acute toxicity test	boric acid	reconstituted	7.0-8.5		25	107	196	527	96 hr LC$_{50}$	Hamilton, S.J. (1995)	A

Table 7. Effects of Boron on Freshwater Aquatic Life

Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp (°C)	Alkalinity (mg/L)	Hardness (mg/L)	Concentration (mg B/L)	Effect	Reference	Chronic, Acute or Indeterminate Study?
Trout	fingerling		Sodium perborate							23.7	80% mortality	McKee and Wolf (1963) *in Butterwick, L. et al (1989)*	I
Xyrauchen texanus (Razorback sucker)	swimup fry	static acute toxicity test	boric acid	reconstituted	7.0-8.5		25	107	196	233	96 hr LC_{50}	Hamilton, S.J. (1995)	A
Xyrauchen texanus (Razorback sucker)	0.9g juvenile	static acute toxicity test	boric acid	reconstituted	7.0-8.5		25	107	196	279	96 hr LC_{50}	Hamilton, S.J. (1995)	A
Plants													
Elodea canadensis			boric acid							1.0	growth inhibited	Nobel et al (1983) *in Maier and Knight (1991)*	C
Elodea canadensis										1.0 ~5.0	NOEC equivalent 21d LC_{50}	Australia and New Zealand Environment and Conservation Council (1999)	C

Table 7. Effects of Boron on Freshwater Aquatic Life

Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp (^oC)	Alkalinity (mg/L)	Hardness (mg/L)	Concentration (mg B/L)	Effect	Reference	Chronic, Acute or Indeterminate Study?
Lemna minor (Duckweed)			boron							≤60	unaffected	Wang (1986) *in Maier and Knight (1991)*	I
Lemna minor (Duckweed)			boric acid							5.0	decrease fresh weight per plant; pH affected bioaccum. of B	Frick (1985) *in Maier and Knight (1991)*	C
Lemna minor (Duckweed)			boric acid		5.0					100	growth inhibited; recovery on transfer to control media	Frick (1985) *in Eisler (1990)*	C
Myriophyllum alterniflourum			boric acid							2.0	growth inhibited	Nobel et al (1983) *in Maier and Knight (1991)*	C
Myriophyllum spicatum (Spiked or Eurasian watermillfoil)										34.2 ~171	NOEC equivalent 32d EC_{50}	Australia and New Zealand Environment and Conservation Council (1999)	C

Table 7. Effects of Boron on Freshwater Aquatic Life

Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp (^oC)	Alkalinity (mg/L)	Hardness (mg/L)	Concentration (mg B/L)	Effect	Reference	Chronic, Acute or Indeterminate Study?
Myriophyllum spicatum			Tetra-borate salt	Fresh-water						40.3	50% inhibition of roots weight after 32 days	Stanley (1974) *in Butterwick, L. et al (1989)*	C
Ranunculus penicillatus			boric acid							1.0	growth inhibited	Nobel et al (1983) *in Maier and Knight 1991)*	C

Table 8. Effects of Boron on Marine Aquatic Life

Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp.(^{o}C)	Salinity (‰)	Concentration (mg B/L)	Effect	Reference	Chronic or Acute?
Invertebrates												
Anthocidaris crassispina (Sea urchin)	embryo								37 75	normal developmnt fatal conc.	Kobayashi (1971) *in Butterwick, L. et al (1989)*	C
Eohaustorius washingtonianus			boric acid	Sea-water	7.8	8.3	15 +/- 1	25	847.7	4d-LC_{50}	MELP (unpubl)	C
Marine Phytoplankton			Sodium metaborate	Sea-water					>1 above backgrnd >10 above backgrnd	production inhibited negligible growth	Stockner, J.G. (1973)	C
Marine phytoplankton (10 species)	Unialgal cultures		boric acid	Sea-water					30	reduction in photosynthesis for 50% of species after 5 days	Subba Rao (1981) *in Butterwick, L. et al (1989)*	C
Marine phytoplankton (19 species)	Axenic cultures		boric acid	Sea-water	7.6-8.0				50 10	reduction in growth rate for 26% of species no effect on growth	Antia and Cheng (1975) *in Butterwick, L. et al (1989)*	C
Purple Sea Urchin			boric acid	Sea-water	7.8	8.6	15	27	503.3	EC_{50}	MELP (unpubl)	C

Table 8. Effects of Boron on Marine Aquatic Life

Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp.(°C)	Salinity (%o)	Concentration (mg B/L)	Effect	Reference	Chronic or Acute?
Vertebrates												
Limanda limanda (Dab)			Sodium metaborate	Sea-water				34.8	88.3 75.7 74.0	24 hr LC$_{50}$ 72 hr LC$_{50}$ 96 hr LC$_{50}$	Taylor et al (1985) *in Butterwick, L. et al (1989) and Eisler (1990)*	A
Oncorhynchus kisutch (Coho salmon)	under yearlings, 1.8-3.8g	Static renewal (daily)	Sodium metaborate	Sea-water			8°C	28	40.0	96 hr LC$_{50}$	Thompson et al (1976) *in Butterwick, L. et al (1989)*	A
Oncorhynchus kisutch (Coho salmon)			boric acid	Sea-water	7.7		15 °C +/- 1 °C	27	122.6	96hr-LC50	MELP (unpubl)	A
Oncorhynchus kisutch (Coho salmon)	advanced fry (1.7g mean weight)	static acute toxicity	boric acid	Brack-ish water	7.79				>1000 600	24hr LC$_{50}$ 96hr LC$_{50}$	Hamilton, S.J. and K.J. Buhl. (1990)	A
Oncorhynchus kisutch (Coho salmon)	under yearlings, 1.8-3.8g	Static renewal (daily)	Sodium metaborate	Sea-water			8°C	28	12.2	283 hr LC$_{50}$	Thompson et al (1976) *in Butterwick, L. et al (1989) and Eisler (1990)*	C

Table 8. Effects of Boron on Marine Aquatic Life

Species	Life Stage	Type of data	Chemical	Water source	pH	Dissolved Oxygen	Temp.(^oC)	Salinity (%o)	Concentration (mg B/L)	Effect	Reference	Chronic or Acute?
Oncorhynchus nerka (Sockeye salmon)		exposure in seawater for 3 weeks		Sea-water					10	maximum residues, in mg/kg FW, were 17 in bone, 12 in kidney, 10 in gill, 9 in liver, 8 in muscle.	Thompson et al (1976) *in Eisler (1990)*	C
Oncorhynchus tshawytscha (Chinook salmon)	advanced fry (1.6g mean weight)	static acute toxicity	boric acid	Brack-ish water	7.79				>1000 600	24hr LC_{50} 96hr LC_{50}	Hamilton, S.J. and K.J. Buhl. (1990)	A

Table 9. Effects of Boron on Terrestrial Mammals and Insects

Species	Boron Compound tested	Type of test; Soil/feed/water characteristics	Concentration	Test response reported	Reference	Chronic or Acute Study?
Mammals						
Dog	boric acid		1.78-2.00 g/kg body wt	LD_{50}	Puls, R. (1994)	A
Dog	pentaborane	inhalation for 15min	92 mg pentaborane/m^3	LC_{50}	EPA (1975) *in Eisler (1990)*	A
Dog	borax and boric acid	2 year study; in diet	350 mg/kg	NOEC	Weir and Fisher (1972)	C
Dog	boron	in diet for 38 weeks	1170 mg B/kg	testicular degeneration, spermatogenesis cessation	Nielsen (1986), Weir and Fisher (1972) *in Eisler (1990)*	C
Dog	borax and boric acid	chronic study; in diet	1540 mg borax/kg (174 mg B/L) 3000 mg boric acid/kg (524 mg B/L)	no adverse effects no adverse effects	Sprague (1972), EPA (1975) *in Eisler (1990)*	C
Guinea pig	decaborane	inhalation for 6h daily, 5-6 exposures	0.018 mg decaborane/m^3	eye inflammation, listlessness, emaciation, convulsions	NAS (1980) *in Eisler (1990)*	C
Mice	boric acid	in diet	1500 mg boric acid/kg (262mg B/kg)	all dead within 10 days	Lizzio (1986) *in Eisler (1990)*	C
Mice	boric acid	13 week study; in diet	34-47 mg/kg/day (1200ppm)	LOEC	NTP (1987)	C
Mice		lifetime exposure; in drinking water	5 mg B/L	no effect on growth, longevity or tumour incidence	Weeth et al (1981), Nielsen (1986) *in Eisler (1990)*	C
Mice	boron	in drinking water	8.1 mg/kg/day	NOEC	Schroeder & Mitchener (1975)	C

Table 9. Effects of Boron on Terrestrial Mammals and Insects

Species	Boron Compound tested	Type of test; Soil/feed/water characteristics	Concentration	Test response reported	Reference	Chronic or Acute Study?
Monkey	pentaborane	inhalation for 2 min	640 mg/m3 pentaborane	LC_{50}	EPA (1975) *in Eisler (1990)*	A
Rat	Sodium borate		2.66-6.08 g/kg body wt	LD_{50}	Puls, R. (1994)	A
Rat	boric acid (oral)		3.16-5.14 g/kg body wt	LD_{50}	Puls, R. (1994)	A
Rat	boric acid	in drinking water for 6 months	0.3 mg boric acid/L (5.24 mg B/L)	no effect on gonadotoxicity	Krasovskii et al (1976) *in Eisler (1990)*	C
Rat	boric acid	in drinking water for 6 months	1.0 mg boric acid/L = 0.05 mg B/kg body wt daily (0.17 mg B/L)	decreased spermatozoid count, reduction in spermatozoid activity	Krasovskii et al (1976) *in Eisler (1990)*	C
Rat	sodium tetraborate	in drinking water 10-14 weeks	3 g sodium tetraborate/L (645 mg B/L)	increase in activity of cerebral succinic dehydrogenase, brain acid proteinase and in brain RNA concentration; decrease in liver cytochrome P-450 activity	Settimi et al (1982) *in Eisler (1990)*	C
Rat	boron	90 day reproductive 60 day reproductive	6.0 mg B/L 25 mg/kg/day 50 mg/kg/day	NOEC NOEC LOEC	Dixon et al (1976) Dixon et al (1979)	C
Rat		in drinking water for 6 months	6 mg B/L = 0.3 mg B/kg body wt daily	gonadotoxicity in male rats; altered enzyme activity levels in blood and liver	Krasovskii et al (1976); Magour et al (1982) *in Eisler (1990)*	C
Rat		free access to drinking water for 90 days	drinking water contained 0.3, 1.0, 6.0 mg B/L	rats refused to drink water at 1.0 or 6.0mg/L	Dixon et al (1976) *in Eisler (1990)*	C

Table 9. Effects of Boron on Terrestrial Mammals and Insects

Species	Boron Compound tested	Type of test; Soil/feed/water characteristics	Concentration	Test response reported	Reference	Chronic or Acute Study?
Rat	boron	in drinking water	75 mg B/L	did not affect growth or reproduction	Green et al (1973) *in NAS (1980)*	C
Rat	borax	in drinking water for 45 days	75 mg B/L	no effect on growth or reproduction	NAS (1980) *in Eisler (1990)*	C
Rat		in drinking water for 21 days	100 mg B/L	tissue B levels in kidney, liver, brain, and blood increased for the first 9 days but returned to normal by day 21 except for blood which continued to rise	Magour et al (1982) *in Eisler (1990)*	C
Rat		in drinking water for extended periods	>150 mg B/L	adverse effects probable	Nielsen (1986) *in Eisler (1990)*	C
Rat	boron	in drinking water	150 mg B/L 300 mg B/L	rats had body weights 7.8 less than control group (LOEC) rats had body weights 19.8% less than control group	Seal & Weeth (1980)	C
Rat	boric acid	in drinking water	170 mg/L 440 mg/L	did not affect rat growth inhibitory effect after 20-30 days	Pfeiffer et al (1945) *in Seal & Weeth (1980)*	C
Rat	boric acid & borax	90 - day test; in diet	175 mg/kg >1750 mg/kg	increased kidney weight (males) severe effects in both sexes	Weir & Fisher (1972)	C
		multigenerational reproductive stdy	17.5 mg/kg/day 58.5 mg/kg/day	NOEC LOEC		

Table 9. Effects of Boron on Terrestrial Mammals and Insects

Species	**Boron Compound tested**	**Type of test; Soil/feed/water characteristics**	**Concentration**	**Test response reported**	**Reference**	**Chronic or Acute Study?**
Rat		in drinking water for 25 days	440 mg B/L	growth inhibition	Seal and Weeth (1980) *in Eisler (1990)*	C
Rat		in diet for 90 days	525 mg B/kg	tolerated	Weir and Fisher (1972) *in Eisler (1990)*	C
Rat	borax or boric acid	in diet for 2 years	350 or 525 mg B/kg 1050 mg B/kg 1170 mg B/kg	no observable effects on fertility, lactation, litter size, weight or appearance testicular degeneration sterility in males and females	Sprague (1972) *in Eisler (1990)*	C
Rat	boric acid or borax	in diet	1000 mg boric acid/borax/kg BW (170 mg B/kg)	weight loss after 1 week on borax diet or 2 weeks on boric acid diet; toxic signs after 3 weeks on both diets	Dani et al (1971) *in Eisler (1990)*	C
Rat		in diet for 2 months	1170 mg B/kg	coarse coat, scaly tails, hunched position, bloody discharge from eyes, depressed hemoglobin and hematocrit	Nielsen (1986) *in Eisler (1990)*	C
Rat		in diet for 25 days	1750 mg B/kg	reduction of 50% in growth rate	Seal and Weeth (1980) *in Eisler (1990)*	C

Table 9. Effects of Boron on Terrestrial Mammals and Insects

Species	Boron Compound tested	Type of test; Soil/feed/water characteristics	Concentration	Test response reported	Reference	Chronic or Acute Study?
Rat, weanlings (11)	boron	in drinking water	300 mg/L	feed consumption of rats drinking water with boron concentration for 49 days was not significantly different from control animals while body weight gain was 21% less.	Green et al (1973) *in Seal & Weeth (1980)*	C
Insects						
Common houseborer	boric acid		430 mg/m^3 wood	adequate wood protection	Sprague (1972) *in Eisler (1990)*	C
Gypsy moth, larvae	boric acid		0.25% boric acid solution (436mg B/L) 0.5% boric acid 1.0% boric acid	no effect on gypsy moth nucleopolyhedrosis virus (NPV) enhanced NPV activity by x2 enhanced NPV activity by x11	Shapiro and Bell (1982) *in Eisler (1990)*	C
Honey bee	boric acid		8.7 mg B/L syrup 17.5 mg B/L syrup	no effect on survival fatal to about 50%	Sprague (1972) *in Eisler (1990)*	C
Houseflies	boric acid	in diet	250-5000 mg B/kg	inhibits reproduction	Sprague (1972) *in Eisler (1990)*	C
Houseflies	isobornyl thiocyanoacetate		0.0273 mg/fly Aerosols >2%	LD_{50} 50% knockdown in 6 minutes	EPA (1975) *in Eisler (1990)*	A

Table 9. Effects of Boron on Terrestrial Mammals and Insects

Species	Boron Compound tested	Type of test; Soil/feed/water characteristics	Concentration	Test response reported	Reference	Chronic or Acute Study?
Termites, 3 species	boric acid		>10,000 mg/m^3 wood	required for wood protection	Sprague (1972) *in Eisler (1990)*	C

Table 10. Effects of Boron on Birds

Species	Boron Compound tested	Type of test; Soil/feed/water characteristics	Concentration	Test response reported	Reference	Chronic or Acute Study?
Livestock						
Chickens	boric acid		3.0 g/kg body wt	LD_{50} (for day old chicks)	Puls, R. (1994)	A
Chickens	boron	in dietary feed	>44 mg/kg	toxic to chick embryos	Puls, R. (1994)	I
Chickens	boron	in dietary feed	250 mg/kg	reduced hatchability but not egg production	Puls, R. (1994)	C
Chickens	boron	in feed	870 mg/kg	10% mortality in chicks	Puls, R. (1994)	I
Chickens	boric acid	in feed	>2500 mg/kg	reduced body weight gain	Puls, R. (1994)	C
Chickens	boric acid		3.6-7.2 kg/9.3m^3 floor space	in litter for 10 days is toxic to chicks	Puls, R. (1994)	C
Chickens	boron	in dietary feed	870 mg/kg	stopped egg laying in 6 days	Puls, R. (1994)	C
Domestic chicken	borax		0.01 mg B/kg body wt 0.5 mg B/kg body wt	LD_1 LD_{50}	Birge and Black (1977) *in Eisler (1990)*	A
Domestic chicken, adult	boric acid	B in diet for 6 days	875 mg B/kg	egg production ceased; production normal 14 days after B withdrawn	Birge and Black (1977) *in Eisler (1990)*	C
Domestic chicken, embryo	boric acid	yolk injection	0.01 mg B/kg body wt 1.0 mg B/kg body wt	LD_1 LD_{50}	Birge and Black (1977) *in Eisler (1990)*	A
Domestic chicken, embryo	boric acid	yolk injection	2.5 mg at 24 hr of development	rumplessness	Landauer (1952) *in Eisler (1990)*	A
Domestic chicken, embryo	boric acid	yolk injection	1.0 mg at 28 hr of development	developmental abnormalities	Schowing and Cuevas (1975) *in Eisler (1990)*	A

Table 10. Effects of Boron on Birds

Species	Boron Compound tested	Type of test; Soil/feed/water characteristics	Concentration	Test response reported	Reference	Chronic or Acute Study?
Domestic chicken, embryo	boric acid	yolk injection	2.0 mg at 28 hr of development	malformations of nervous system, eyes and spinal cord	Schowing et al (1976) *in Eisler (1990)*	A
Domestic chicken, embryo	boric acid	yolk injection	2.5 mg at 84 hr of development	feet defects	Landauer (1952) *in Eisler (1990)*	A
Domestic chicken, embryo	boric acid	yolk injection	2.5 mg at 96 hr of development	skeletal deformities, cleft palate, missing toes, eye deformities	Landauer (1953a, b, c) *in Eisler (1990)*	A
Domestic chicken, embryo	boric acid	yolk injection	15.8 mg B/kg egg at 96 h of development	LD50 (96hr). 70-85% of survivors at age 18 days had edema, inhibited feather growth, pale body coloration, and reduced body wt.	Ridgway and Karnofsky (1952) *in Eisler (1990)*	A
Duck	boron	in dietary feed	1000-1600 mg/kg	produced 10-21% mortality in ducklings	Puls, R. (1994)	C
Duck	boron		<300 mg/kg	no effect on hatchability	Puls, R. (1994)	C
Duck	boron	in dietary feed	1000 mg/kg	Reduced hatching success of fertile eggs to about 52%, mortality occurring mainly during the 2nd half of incubation; increased mortality rate of ducklings during the first week of life; reduced the number of ducklings produced per female	Puls, R. (1994)	C

Table 10. Effects of Boron on Birds

Species	Boron Compound tested	Type of test; Soil/feed/water characteristics	Concentration	Test response reported	Reference	Chronic or Acute Study?
Wildlife						
Mallard Duck (adult female)	powdered boric acid	groups separated by sex and fed diets for 3 weeks; duck developer mash supplemented with different concentrations of boric acid	1000 mg/kg	Decreased hatching success (52%) and duckling survival; body weights lower; liver and brain weights lower	Smith, G.J. and V.P. Anders (1989)	C
Mallard Ducklings		dietary boron	100 mg/kg	Decreased growth and physiological effects	Hoffman, D.J et al (1990)	C
			400 mg/kg or greater	altered brain biochemistry, resulting in increased resting time - decreased energy levels could further decrease duckling survival in a natural environment		
			1600 mg/kg	10 % mortality & decreased overall growth and rate of growth		

Table 10. Effects of Boron on Birds

Species	Boron Compound tested	Type of test; Soil/feed/water characteristics	Concentration	Test response reported	Reference	Chronic or Acute Study?
Mallard Ducks		dietary boron	900 mg/kg	weight loss in females between treatment onset and pairing; reduced hatching success by more than 42%; egg weight and fertility were lower; duckling weight and growth reduced; 47% reduction in number of ducklings produced per female	Stanley, T.R et al. (1996)	C

Table 11. Effects of Boron on Irrigated Crops and Terrestrial Plants

Crop	Soil Type	Location	Concentration (mg B/L)	Effect	Reference
Crops					
Alfalfa			850-975 mg B/kg DW plant	reduced yield	Gestring and Soltanpour (1987) *in Eisler (1990)*
Alfalfa		Carson City, Nevada	0.5-2.1 (wastewater irrigation)	no reported effect	Olson and Fuog (1981) *in Butterwick, L. et al (1989)*
Barley, wheat, corn	sandy loam	Mess, Arizona	0.44 (wastewater irrigation)	no reported effect	Stone (1980) *in Butterwick, L. et al (1989)*
Beet		USA	5.0 (as soil boron concentration	optimal growth	Sprague (1972) *in Eisler (1990)*
			15 (as soil boron concentration)	injury evident	
Broccoli			0.08	chlorophyll levels and net photosynthetic rates were significantly lower than those for plants grown in 0.41-0.81mg B/L solutn.	Petracek and Sams (1987) *in Eisler (1990)*
			4.1 and 8.1	leaf damage evident; lower chlorophyll levels and lower net photosynthetic rate than 0.4 and 0.8mg B/L groups	
Citrus		Santa Ana River Valley, Calif.	0.5-1.7 (wastewater irrigation)	no reported effect	Eccles (1979) *in Butterwick, L. et al (1989)*
Citrus		Florida	0.15-0.8 (wastewater irrigation)	no reported effect	Carriker and Brezonik (1978) *in Butterwick, L. et al (1989)*

Table 11. Effects of Boron on Irrigated Crops and Terrestrial Plants

Crop	Soil Type	Location	Concentration (mg B/L)	Effect	Reference
Citrus	sandy loam	Sicily	2.0 (wastewater irrigation)	toxicity symptoms noted	Indelicato et at (1981) *in Butterwick, L. et al (1989)*
Corn		USA	1.0 (as soil boron concentration) 5.0 (as soil boron concentration)	optimal growth injury evident	Sprague (1972) *in Eisler (1990*
Corn, alfalfa	loam	Roswell, New Mexico	0.34 (wastewater irrigation)	no reported effect	Koerner and Hans (1979) *in Butterwick, L. et al (1989)*
French bean	fly ash	Australia	3 mg hot water soluble	toxic, residues >209mg/kg DW	Aitken and Bell (1985) *in Eisler (1990*
Grain		Santa Rosa, Calif.	0.53 (wastewater irrigation)	no reported effect	Stenquist et al (1979) *in Butterwick, L. et al (1989)*
Lemon		USA	0.03-0.04 (as soil boron concentration) 1.0 (as soil boron concentration)	optimal growth injury evident	Sprague (1972) *in Eisler (1990)*
Misc. fruit and vegetables		Valley of Mexico	1.89-2.56 (wastewater irrigation)	no reported effect	Mendosa Gamaz and Flores Herrera (1981) *in Butterwick, L. et al (1989)*
Orchards, green areas		Goleta, Calif.	0.5-0.7 (wastewater irrigation)	no reported effect	Stenquist et al (1979) *in Butterwick, L. et al (1989)*
Pasture, trees, sugarcane		Pretoria, Africa	0.1-0.3 (wastewater irrigation)	no reported effect	Odendaal and van Vuuren (1979) *in Butterwick, L. et al (1989)*

Table 11. Effects of Boron on Irrigated Crops and Terrestrial Plants

Crop	Soil Type	Location	Concentration (mg B/L)	Effect	Reference
Pear			82-164 kg B/ha applied to soil around pear trees in a nonirrigated orchard over a 6 year period	toxicity observed during application and during 4 years postapplication. Toxicity was associated with residues in blossom clusters and fruit. Within 5 years postapplication, soil B levels were <2mg/kg, and all visible signs of toxicity had disappeared.	Crandall et al (1981) *in Eisler (1990*
Rice			2.5-5.0	toxic	Cayton (1985) *in Eisler (1990*
Rye	sandy clay loam	Athens, Georgia	1.2 (wastewater irrigation)	no reported effect	King and Morris (1972) *in Butterwick, L. et al (1989)*
Rye, corn, sorghum, perennial grasses, legumes	hard clay	Lansing, Michigan	0.3 (wastewater irrigation)	no reported effect	Ball (1977) *in Butterwick, L. et al (1989)*
Soybean	soils amended with scrubber sludge residues from coal fired power plant for 2-3 years		4.1 g B/kg	higher sludge B levels of 2 mg B/kg soil surface at year 1, and 1.2mg B/kg at year 2 produced signs of B toxicity, including decreased growth and elevated residues in leaf and in seeds	Ransome and Dowdy (1987) *in Eisler (1990)*
Sugar beet	calcareous	Tel-Adashim, Israel	0.38-0.42 (wastewater irrigation)	no reported effect	Feigin (1979) *in Butterwick, L. et al (1989)*

Table 11. Effects of Boron on Irrigated Crops and Terrestrial Plants

Crop	Soil Type	Location	Concentration (mg B/L)	Effect	Reference
Sunflower			10 50	tolerated level adversely affects phospholipid composition and synthesis in roots and microsomes from seedlings by inhibition of choline phosphotransferase	Belver and Donaire (1987) *in Eisler (1990)*
Tomatoes, broccoli, spinach	clay loam	Camarillo, Calif.	0.85 (wastewater irrigation)	no reported effect	Stone and Rowlands (1980) *in Butterwick, L. et al (1989)*
Various	sandy loam	Tula River Valley, Mexico	1.3-2.8 (wastewater irrigation)	no reported effect	Burton (1982) *in Butterwick, L. et al (1989)*
Various truck crops	clay loam, sandy clay loam, clay	Mexico City, Mexico	1.5-2.8 (wastewater irrigation)	no reported effect	Giordana et al (1975) and Mendoza (1981) *in Butterwick, L. et al (1989)*
Other Plants					
Bermuda grass native vegetation	fine loam	Salt River, Arizona	0.45-0.85 (wastewater irrigation)	no reported effect	Bouwer et al (1980, 1981) *in Butterwick, L. et al (1989)*
Big Leaf Maple	saturated soil extracts	California	0.9-5.4	reduced growth; >25% foliar damage; leaf residues of 76-324mg B/kg ash wt.	Glaubig and Bingham (1985) *in Eisler (1990)*
Desert chaparral	sandy loam	San Bernadino	0.2-0.3 (wastewater irrigation)	no reported effect	Younger (1974) *in Butterwick, L. et al (1989)*
Digger pine	saturated soil extracts	California	13-17	growth reduction; foliar damage >25%; needle residues 1242-1512mg B/kg ash wt	Glaubig and Bingham (1985) *in Eisler (1990*

Table 11. Effects of Boron on Irrigated Crops and Terrestrial Plants

Crop	Soil Type	Location	Concentration (mg B/L)	Effect	Reference
Forest, corn, wheat, grass	silt/clay loam and sand loam	State College, Pennsylvania	0.21-0.42 (wastewater irrigation)	no reported effect	Kardos (1974) *in Butterwick, L. et al (1989)*
Grass meadows	sandy loam	Wroclaw, Poland	0.13-0.24 (wastewater irrigation)	no reported effect	Cebula (1980) and Hossner et al (1978) *in Butterwick, L. et al (1989)*
Grasses	gravely sand and loam	Hollister, Calif.	1.4 (wastewater irrigation)	no reported effect	Pound et al (1978) *in Butterwick, L. et al (1989)*
Madrone	saturated soil extracts	California	2.2-5.4	growth inhibition; >25% foliar damage; leaf residues of 216-540mg B/kg ash wt.	Glaubig and Bingham (1985) *in Eisler (1990)*
Red pine	loamy clay	Michigan	0.9 (wastewater irrigation)	toxicity symptoms noted	Cuadra Moreno (1981) and White et al (1975) *in Butterwick, L. et al (1989)*
Rhodes grass	calcareous	Zora, Israel	0.22-0.40 (wastewater irrigation)	no reported effect	Feigin (1979) *in Butterwick, L. et al (1989)*
Rhodes grass	fly ash	Australia	3 mg hot water soluble	toxic; residues >149 mg/kg dry wt.	Aitken and Bell (1985) *in Eisler (1990*

Table 12. Effects of Boron on Livestock

Species	Boron Compound tested	Type of test; Soil/feed/water characteristics	Concentration	Test response reported	Reference	Chronic or Acute Study?
Cattle	borax	Accidental ingestion	250 g B (1kg borax)	death	Brockman et al (1985) *in Eisler (1990)*	A
Cattle	boron	fertiliser w/ 20.5% boron		poisoned cows	Puls, R. (1994)	A
Cattle	boron		200-600 mg B/kg body wt	toxic dose	Brockman et al (1985) *in Eisler (1990)*	I
Cattle	boron		200-600 mg B/kg body wt	lethal dose	Puls, R. (1994)	I
Cattle	borax	in diet	20 g borax daily (2.27 g B)	milk B residues increased from <1.0mg/L to >3mg/L	Nielsen (1986) *in Eisler (1990)*	C
Cattle	boron	in drinking water	150-300 mg/L	toxic signs in 30 days	Puls, R. (1994)	C
Cattle	borax	in diet for 40 days	2-2.5 g B	no observable effects; all B excreted, mostly in urine	Sprague (1972) *in Eisler (1990)*	C
Cattle	boron	in drinking water	29 mg B/L and higher	when given the choice, cattle preferred tap water to drinking water supplemented with B compounds	Green and Weeth (1977) *in Eisler (1990)*	C
Cattle	boric acid	in drinking water	120 mg B/L	no overt signs of toxicosis with 10 day exposure	Weeth et al (1981) *in Butterwick, L. et al (1989)*	C
Cattle	borax	in drinking water for 10 days	120 mg B/L	no effect on feed or water consumption; no overt signs of toxicosis	Weeth et al (1981) *in Eisler (1990)*	C

Table 12. Effects of Boron on Livestock

Species	Boron Compound tested	Type of test; Soil/feed/water characteristics	Concentration	Test response reported	Reference	Chronic or Acute Study?
Cattle	borax	in drinking water for 30 days	150 mg B/L = 15.3mg B/kg body wt daily	decreased feed consumption, weight loss, edema, inflammation of legs, daily elevated plasma B levels of 1.2 mg/L; abnormal blood chemistry	Green and Weeth (1977), Weeth et al (1981), NAS (1980), Seal and Weeth (1980), Nielsen (1986) *in Eisler (1990)*	C
Cattle, adult in mid lactation (2)	borax	added to diets for 42 days	145-157 mg/kg	no adverse effect	Owen (1944) *in NAS (1980)*	C
Cattle, yearling (12)	boric acid	in drinking water for 30 days	150-300 mg B/L	swelling and irritation of legs, lethargy, diarrhoea with 30 day exposure	Green and Weeth (1977) *in Butterwick, L. et al (1989)*	C
Goat			1.8 g/kg body wt	produced toxic signs, but not death	Puls, R. (1994)	I
Goat	boron	fertiliser containing 20.5% B (single dose)	3.6 g/kg body wt	caused death in 8hrs	Puls, R. (1994)	A
Goat			400 mg B/kg body wt	toxic	Puls, R. (1994)	I

References in main document

Table 13. Boron Guidelines for Drinking Water

Guideline Statement	Guideline Value	Jurisdiction	Date	Reference
The interim maximum acceptable concentration of boron in drinking water is 5.0 mg/L	5.0 mg/L	Saskatchewan, Canada		
Recommended	<0.3 mg B/L	USA	1976	Krasovskii, G.N. et al. (1976) *in Eisler (1990)*
USSR	<0.5 mg B/L	USSR	1980	Seal & Weeth (1980) *in Eisler (1990)*
USA	<1.0 mg B/L	USA	1980	NAS (1980), Green & Weeth (1977) *in Eisler (1990)*
"Safe"	<20 mg B/L	USA	1987	Papachristou, E. et al (1987), Seal & Weeth (1980) *in Eisler (1990)*
No toxic effects	20-30 mg B/L	USA	1987	Papachristou, E. et al (1987) *in Eisler (1990)*
On the basis of the results of chronic experiments, 0.001 mg/L is recommended as the hygienic standard for cadmium in water and 0.5 mg/L for boron.	0.5 mg/L	USA	1976	Krasovskii, G.N. et al (1976)
Recommended maximum levels (Human)	<5.0 mg/L		1994	Puls, R. (1994)
The concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic effects for up to 5 consecutive days of exposure, with a margin of safety.	4 mg/L (for 10kg child)	USA	1996	EPA, Office of Water (1996)
The concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic effects for up to 14 consecutive days of exposure, with a margin of safety.	0.9 mg/L (for 10kg child)	USA	1996	EPA, Office of Water (1996)
The concentration of a chemical in drinking water that	0.9 mg/L (for 10kg child)	USA	1996	EPA, Office of Water (1996)

Table 13. Boron Guidelines for Drinking Water

Guideline Statement	Guideline Value	Jurisdiction	Date	Reference
is not expected to cause any adverse noncarcinogenic effects for up to approx. 7 years (10% of an individuals lifetime) of exposure, with a margin of safety.	3.0 mg/L (for 70kg adult)			
Reference Dose - an estimate of a daily exposure to the human population that is likely to be without appreciable risk of deleterious effects over a lifetime.	0.9 mg/kg/day (for 70kg adult)	USA	1996	EPA, Office of Water (1996)
Drinking Water Equivalent Level - a lifetime exposure concentration protective of adverse, non-cancer health effects, that assumes all of the exposure to a contaminant is from a drinking water source.	30.6 mg/L (for 70kg adult)	USA	1996	EPA, Office of Water (1996)
Quality criteria for general use	1.0 mg/L	Illinois, USA	1986	EPA (1988)
Quality criteria for general use	1.0 mg/L	Nevada, USA	1985	EPA (1988)
Quality criteria for classes I, IA, II, and III (incl. drinking water)	0.75 mg/L (dissolved)	North Dakota, USA	1985	EPA (1988)
Quality criteria for all water uses	0.5 mg/L	Oregon, USA- specific to some basins	1986	EPA (1988)
Quality criteria for surface waters intended for use as a raw water source for public water supply	1.0 mg/L	Puerto Rico	1983	EPA (1988)
Maximum detection level for drinking water contaminants (boron)	0.006 mg/L	Colorado, USA	1997	CDPHE (1997)

Table 14. Boron Guidelines for Freshwater Aquatic Life

Guideline Statement	Guideline Value	Jurisdiction	Date	Reference
Data available suggest that the no-observable-effect level is 13.6 mg B/L for freshwater organisms (invertebrates).	13.6 mg B/L	USA	1990	Eisler, R. (1990)
Nonhazardous levels in water Fish	1 mg B/L	USA	1976	Thompson, J.A.J. et al (1976) *in Eisler, R. (1990)*
Aquatic plants	4 mg B/L	USA	1987	Papachristou, E. et al (1987) *in Eisler, R (1990)*
"Safe" levels in water Largemouth Bass, *Micropterus salmoides*	<30 mg B/L	USA	1972	Sprague, R.W. (1972) *in Eisler, R. (1990)*
Bluegill, *Lepomis macrochirus*	<33 mg B/L	USA	1977	Birge & Black (1977), Sprague, R.W. (1972) *in Eisler, R. (1990)*
Concentration of between 0.75 and 1.0 mg/L is determined to be a reasonable, environmentally acceptable limit for boron in aquatic systems	0.75-1.0 mg/L	USA	1992	Black, J.A. et al (1993)
A freshwater high reliability trigger value for boron of 370 µg/L was calculated using the statistical distribution method at 95% protection.	0.37 mg/L	Australia	2000	Australia and New Zealand Environment and Conservation Council (2000)
National criteria & criteria for coldwater adapted species	0.01 mg/L (acute effect value) 0.001 mg/L (chronic effect value)	South Africa	1996	Roux, D.J. et al (1996)
Effluent limitations for subsurface waters (aquifer) for aquatic life protection	2.0 mg/L	Missouri, USA	1988	EPA (1988)
Effluent limitations for groundwater for aquatic life protection	0.750 mg/L	Missouri, USA	1988	EPA (1988)
Quality criteria for Class AA (Aquatic) use	10.0 mg/L	New York State, USA	1985	EPA (1988)

Table 14. Boron Guidelines for Freshwater Aquatic Life

Guideline Statement	Guideline Value	Jurisdiction	Date	Reference
Quality criteria for the protection of freshwater aquatic life	5.0 mg/L	Mariana Islands	1986	EPA (1988)

Table 15. Boron Guidelines for Marine Aquatic Life

Guideline Statement	Guideline Value	Jurisdiction	Date	Reference
Data available suggest that the no-observable-effect level is 37 mg B/L for marine biota (invertebrates).	37 mg B/L	USA	1990	Eisler, R. (1990)
Phytoplankton can tolerate up to 10 mg inorganic B/L in the absence of stress from pH adversity and nutrient deficiency	<10 mg B/L (inorganic)	USA	1990	Eisler, R. (1990)
Nonhazardous levels in water Fish, oysters (*Crassostrea gigas*)	1 mg B/L	USA	1976	Thompson, J.A.J. et al (1976) *in Eisler, R. (1990)*
Aquatic plants	4 mg B/L	USA	1987	Papachristou, E. et al (1987) *in Eisler, R (1990)*
Adverse effects, sensitive species coho salmon, *Oncorhynchus kisutch*	12 mg B/L	USA	1976	Thompson, J.A.J. et al (1976) *in Eisler, R. (1990)*
Sockeye salmon, *O. nerka*	10 mg B/L	USA	1976	Thompson, J.A.J. et al (1976) *in Eisler, R. (1990)*
Data were available for boron for only 2 species of fish, 4-12d LC_{50}, 12 200-88 300 µg/L. There were insufficient data to derive a guideline trigger level and it is recommended that the established background level in seawater, which is around 5100 µg/L be adopted as a low reliability trigger value for marine waters.	5.1 mg/L	Australia	2000	Australia and New Zealand Environment and Conservation Council (2000)
Quality criteria for the protection of marine aquatic life	5.0 mg/L	Guam	1984	EPA (1988)
Quality criteria for the protection of marine aquatic life	5.0 mg/L	Mariana Islands	1986	EPA (1988)
Quality criteria for coastal	4.8 mg/L	Puerto Rico	1983	EPA (1988)

Table 15. Boron Guidelines for Marine Aquatic Life

Guideline Statement	Guideline Value	Jurisdiction	Date	Reference
waters for use in propagation, maintenance and preservation of desirable species				
Quality criteria for the protection of the marine aquatic life	5.0 mg/L	Trust Territories, USA	1986	EPA (1988)

Table 16. Boron Guidelines for Wildlife

Guideline Statement	Guideline Value	Jurisdiction	Date	Reference
Data are unavailable on boron effects on terrestrial wildlife. Until these data become available, it seems reasonable to apply the same criteria proposed for livestock protection to mammalian wildlife; that is, diets should contain more than 0.4 mg B/kg dry weight but less than 100 mg/kg, and drinking water <5mg/L.	diet: >0.4 mg B/kg dry weight & <100 mg/kg drinking water: <5 mg/L	USA	1990	Eisler, R. (1990)
Waterfowl - Diet No observed adverse effects	<13 mg/kg fresh weight (FW)	USA	1990	Hoffman, D.J. et al (1990) *in Eisler, R. (1990)*
Adverse effects	30-100 mg/kg FW	USA	1990	Hoffman, D.J. et al (1990), Smith, G.J. et al (1989) *in Eisler, R. (1990)*
Fatal	1000 mg/kg FW	USA	1989	Smith, G.J. et al (1989) *in Eisler, R. (1990)*

Table 17. Boron Guidelines for Irrigation

Guideline Statement	Guideline Value	Jurisdiction	Date	Reference
The concentration of total boron in irrigation water should not exceed 0.5 mg/L for sensitive plants, but could be as high as 6.0 mg/L for tolerant plants.	0.5 – 6.0 mg/L	Canada	1987	CCREM (1987), CCME (1999)
Recommends 0.75 mg/L for waters used continuously on all soils and 2.0 mg/L for waters used up to 20 years on fine-textured soils of pH 6.0-8.5.	0.75 – 2.0 mg/L	Ontario, Canada	1984	Ontario Ministry of the Environment (1984)
Recommends 0.5 mg/L for irrigation water used as a sole source, 1.0 mg/L for supplemental irrigation and 2.0 mg/L for protection of medium to fine-textured soils up to 20 years.	0.5 – 2.0 mg/L	Manitoba, Canada	1983	Williamson (1983)
Water quality guidelines for agricultural uses	0.5 – 6.0 mg/L	Alberta, Canada	1999	Alberta Environment (1999)
The maximum concentrations of boron recommended for irrigation water on all types of soil are 2.0 mg/L for tolerant crops, 1.0 mg/L for semitolerant plants and 0.3 mg/L for sensitive crops	0.3 – 2.0 mg/L	Australia	1974	Hart (1974)
The concentration of boron in irrigation waters and soils should not exceed the desirable contaminant concentration of 0.5 mg/L	0.5 mg/L	Australia	1999	Australia and New Zealand Environment and Conservation Council (1999)
Sensitive crops	0.3-1.25 mg B/L	USA	1987	Sprague, R.W. (1972), Papachristou, E. et al (1987), EPA (1975) *in Eisler, R. (1990)*
Semitolerant crops	0.67-2.5 mg B/L	USA	1987	Sprague, R.W. (1972), Papachristou, E. et al (1987), EPA (1975) *in*

Table 17. Boron Guidelines for Irrigation

Guideline Statement	Guideline Value	Jurisdiction	Date	Reference
				Eisler, R. (1990)
Tolerant crops	1-4 mg B/L	USA	1987	Sprague, R.W. (1972), Papachristou, E. et al (1987), EPA (1975) *in Eisler, R. (1990)*
Maximum safe concentration	4 mg B/L	USA	1987	Papachristou, E. et al (1987) *in Eisler, R. (1990)*
The following numeric standard shall not be exceeded: Dissolved boron	0.75 mg/L	New Mexico Streams, USA	1995	New Mexico Water Quality Control Comm. (1995)
Irrigation waters containing more than 1.0 ppm boron (B) may cause accumulation of toxic levels for sensitive crops.	1.0 mg/L	Nebraska, USA	1977	Hergert, G.W. et al (1977)
Nature of Crop Sensitive Semitolerant Tolerant	 0.3-1 mg/L 1-2 mg/L 2-4 mg/L	USA	1935	Eaton, F.M. (1935) *in Butterwick, L. et al (1989)*
Sensitive Semitolerant Tolerant	0.5-1 mg/L 1-2 mg/L 2-10 mg/L	Food and Agriculture Organisation (UNESCO)	1976	Gupta, I.C. (1983) *in Butterwick, L. et al (1989)*
All crops	0.7 mg/L	Israel		Gupta, I.C. (1983) *in Butterwick, L. et al (1989)*
All soils/long term Fine textured soils for 20 years	1.0 mg/L 2.0 mg/L	USA	1972	Gupta, I.C. (1983) *in Butterwick, L. et al (1989)*
All soils/long term Fine textured neutral and alkaline soils for 20 years	0.75 mg/L 2.0 mg/L	USA	1973	Gupta, I.C. (1983) *in Butterwick, L. et al (1989)*
Degree of problem No problem Increasing problem Severe problem	 <0.5 mg/L 0.5-2.0 mg/L 2.0-10.0 mg/L	Food and Agriculture Organisation	1976	Ayers, R.S et al (1976) *in Butterwick, L. et al (1989)*
Permissible Limits Sensitive crop (pecan, walnut, Jerusalem artichoke, navy bean,	0.33-0.67 mg/L (good irrigation quality) 0.67-1.00 mg/L (permissible irrigation quality)	USA	1990	van der Leeden (1990) *in Texas A&M University Agriculture Program*

Table 17. Boron Guidelines for Irrigation

Guideline Statement	Guideline Value	Jurisdiction	Date	Reference
American elm, plum, pear, apple, grape, fig, cherry, peach, apricot, orange, avocado, grapefruit, lemon)	1.00-1.25 mg/L (doubtful irrigation quality) >1.25 mg/L (unsuitable irrigation quality)			
Semitolerant (sunflower, potato, cotton, tomato, sweetpea, radish, field pea, olive, barley, wheat, corn, milo, oat, zinnia, pumpkin, bell pepper, sweet potato, lima bean)	0.67-1.33 mg/L (good irrigation quality) 1.33-2.00 mg/L (permissible irrigation quality) 2.00-2.50 mg/L (doubtful irrigation quality) >2.50 mg/L (unsuitable irrigation quality)	USA	1990	van der Leeden (1990) *in Texas A&M University Agriculture Program*
Tolerant (asparagus, palm, date palm, sugar beet, mangel, garden beet, alfalfa, gladiolus, broadbean, onion, turnip, cabbage, lettuce, carrot)	1.00-2.00 mg/L (good irrigation quality) 2.00-3.00 mg/L (permissible irrigation quality) 3.00-3.75 mg/L (doubtful irrigation quality) >3.75 mg/L (unsuitable irrigation quality)	USA	1990	van der Leeden (1990) *in Texas A&M University Agriculture Program*
Quality Criteria for long term irrigation on sensitive crops	0.75 mg/L	USA	1986	EPA (1988)
Quality Criteria for agriculture irrigation	1.0 total residues mg/L	Arizona, USA	1986	EPA (1988)
Quality criteria for agriculture irrigation	0.75 mg/L 30 day average	Colorado, USA	1986	EPA (1988)
Quality criteria for agriculture (Class IV)	0.75 mg/L	Florida, USA	1986	EPA (1988)
Quality criteria for agriculture irrigation	0.75 mg/L	Kansas, USA	1987	EPA (1988)
Quality criteria for irrigation	0.75 mg/L	Missouri, USA	1988	EPA (1988)
Quality criteria for irrigation	1.0 mg/L	Humbolt River, Nevada, USA	1985	EPA (1988)
Quality criteria for agriculture and wildlife (Class 4A)	0.5mg/L	Minnesota, USA	1982	EPA (1988)

Table 18. Boron Guidelines for Livestock Water Supply

Guideline Statement	Guideline Value	Jurisdiction	Date	Reference

Table 18. Boron Guidelines for Livestock Water Supply

Guideline Statement	Guideline Value	Jurisdiction	Date	Reference
The boron concentration in water used by livestock should not exceed 5.0 mg/L	5.0 mg/L	USA	1973	NAS (1973)
The boron concentration in water used by livestock should not exceed 5.0 mg/L	5.0 mg/L	Ontario, Canada	1984	Ontario Ministry of the Environment (1983)
The boron concentration in water used by livestock should not exceed 5.0 mg/L	5.0 mg/L	Manitoba, Canada	1983	Williamson (1983)
Maximum allowable	5 mg B/L	USA	1981	Weeth, H.J. et al (1981), NAS (1980), Seal & Weeth (1980), Green & Weeth (1977) *in Eisler, R. (1990)*
Maximum tolerated	40 mg B/L	USA	1980	Seal & Weeth (1980) *in Eisler, R. (1990)*
"Safe"	40-150 mg B/L	USA	1977	Green & Weeth (1977) *in Eisler, R. (1990)*
Adverse effects	>150 mg B/L	USA	1986	Nielsen, F.H. (1986) *in Eisler, R. (1990)*
The following numeric standards shall not be exceeded: Dissolved boron	5.0 mg/L	New Mexico Streams, USA	1995	New Mexico Water Quality Control Comm. (1995)
Recommended maximum levels (Livestock)	<5.0-30 mg/L		1994	Puls, R. (1994)
Quality criteria for agriculture livestock	5.0 mg/L	Kansas state, USA	1987	EPA (1988)
If the concentration of boron in water exceeds 5 mg/L, the total boron content of the livestock diets should be investigated. Higher concentrations in water may be tolerated for short periods of time.	5.0 mg/L	Australia	1999	Australia and New Zealand Environment and Conservation Council (1999)

Table 19. Boron Guidelines for Recreation

Guideline Statement	Guideline Value	Jurisdiction	Date	Reference
Quality criteria for primary contact recreation	10.0 mg/L	New York State, USA	1985	EPA (1988)
Quality criteria for primary and secondary contact recreation and shellfishing	1.0 mg/L	New York State, USA	1985	EPA (1988)
Quality criteria for coastal waters intended for use for recreation	4.8 mg/L	Puerto Rico	1983	EPA (1988)
Quality criteria for recreation and aesthetic enjoyment of marine waters	5.0 mg/L	Trust Territories, USA	1986	EPA (1988)