UNITED STATES DEPARTMENT OF THE
INTERIOR

NATIONAL IRRIGATION WATER
QUALITY PROGRAM
INFORMATION REPORT NO. 3

Guidelines for Interpretation of the Biological Effects of Selected Constituents in Biota, Water, and Sediment

Boron

Participating Agencies:

Bureau of Reclamation
U.S. Fish and Wildlife Service
U.S. Geological Survey
Bureau of Indian Affairs

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Boron

Description

Boron (B) is a metalloid, with properties intermediate between those of carbon and aluminum. Like aluminum, it has an oxidation state of +3 in all of its chemical compounds, and it is an electrical conductor in its pure form. Like carbon, though, it can sometimes form complex chains and rings, and its crystalline form is nearly as hard as diamond. Boron has an atomic number of 5 and an atomic weight of 10.81. It melts at 2,180°C. Boron is found as a hard black solid and as an amorphous blackish-brown powder, although the more common boron salts are generally white or pale shades of yellow, blue, green, or gray. (Pais and Jones 1997.)

Occurrence

Boron is widespread in the environment but generally occurs in low concentrations; it constitutes only 3 mg/kg of the Earth's crust and occurs naturally only in combined form, usually as borax ($Na_2B_4O_7 \cdot 10H_2O$), colemanite ($Ca_2B_6O_{11} \cdot 5H_2O$), boronatrocalcite ($CaB_4O_7NaBO_2 \cdot 8H_2O$), or boracite ($Mg_7Cl_2B_{16}O_{30}$) (EPA 1975; NAS 1980). Areas with the highest natural inputs of boron to the environment are the Mojave Desert, California, the plateau of the Alpine-Himalayan system, and the high plateau of the Andes (Butterwick et al. 1989). The brines of Borax and Mono Lakes in California are rich in boron due to arid conditions and high evaporative concentration (Livingstone 1963). Boron compounds usually are degraded or transformed to boric acid and borates, which are the main boron compounds of ecological significance (Sprague 1972).

In natural freshwater ecosystems, surface water concentrations of boron rarely exceed 1 mg/L and are usually less than 0.1 mg/L; however, in systems where boron has been mobilized by human activities, the concentrations may be much higher (Maier and Knight 1991). In a survey of 1,546 river- and lake-water samples from throughout the United States, the mean concentration of boron was 0.1 mg/L, with 5.0 mg/L being the maximum (Powell et al. 1997). Groundwater boron concentrations are usually <0.5 mg/L worldwide; in the United States, concentra-tions can be as high as 5 mg/L in ground-water. Aquatic fauna can usually tolerate up to 10 mg B/L in water for extended periods of time without adverse effects (Eisler 1990). Recently, South Africa has developed a water-quality criterion of 1 mg B/L to protect aquatic ecosystems (including terrestrial animals that use them). Recognizing that boron sensitivity of plants is greater than that of animals, South Africa's water-quality criterion was based on calculation of a "final plant value" (Roux et al. 1996).

Boron concentrations in U.S. irrigation water typically range from <0.1 to 0.3 mg/L (Adriano 1986). Some irrigation water (especially pumped groundwater) used in the western San Joaquin Valley, California, contain far greater concentrations (Shelton and Miller 1988); boron concentrations in the San Luis Drain and Kesterson Reservoir were 11–18 and 13–65 mg/L, respectively (USBR 1986). Agricultural drain water contaminated with boron is considered potentially harmful to waterfowl and other wildlife populations throughout areas of the Western United States (Smith and Anders 1989).

Boron compounds enter the North American environment at an estimated rate of 32,000 tons annually, primarily from laundry products, irrigation drain water, fertilizers and other agricultural chemicals, coal combustion, and mining and processing (Eisler 1990). Boron compounds also are used as fire retardants and leather-tanning compounds and have even been used in rocket fuels. Elemental boron is frequently used for neutron absorption in nuclear reactors, and sodium borohydride is used by the pulp and paper industry in the production of the whitening agent sodium dithionite (Thurston et al. 1979). The United States supplies about 70 percent of the global boron demand.

Summary of Effects

Plants in general are far more sensitive than animals to boron toxicity, and there is a large literature base documenting boron's effects on plants, especially crop plants. The exact mechanism of boron toxicity in animals is not fully understood. It is not known whether boric acid, the borate ion, or some other boron complex is the toxic boron compound (Maier and Knight 1991). Boric acid and the borate ion exhibit remarkable stability in natural aquatic systems, and any boron that is not taken up by plants and/or animals will tend to accumulate and remain bioavailable over extended periods of time (Perry et al. 1994).

Considering the paucity of data on boron toxicity, effect levels can be predicted only tentatively at this time. These tentative predictions are listed in table 6.

Study Approaches

The majority of papers reviewed for this report were laboratory studies dealing with boron effects on plants and birds. Most of the plant literature concerned toxicity or

Table 6.—Predicted boron effect levels

Medium	No effect	Level of concern	Toxicity threshold	Explanation
Water (mg/L)	0.5	0.5–10	10	For crops and aquatic plants (Perry et al. 1994)
	6	6–13	13	For aquatic invertebrates (NOAEL and LOAEL for *Daphnia magna*)
	5	5–25	25	For fish (*viz.*, catfish and trout embryos; Birge and Black 1977; Perry et al. 1994)
			<200	For amphibians (LC100 for leopard frog embryos)
Bird eggs (mg/kg fw)	13	13–20	20	Smith and Anders (1989), Stanley et al. (1996); 20 = EC10 for viability of mallard eggs
Waterfowl diet (mg/kg)		>30		LOAEL for mallards; impaired growth of ducklings
Mammal diet (mg/kg bw/day)		>80		LOAEL for rodents; decreased fetal body weight

deficiency in crops and is not comprehen-sively summarized in this report. The crop literature has been summarized compre-hensively by Eaton (1935) and most recently by Perry et al. (1994). Avian literature consisted mostly of studies done on mallards from the late 1980s to early 1990s. Some poultry literature was reviewed, but the bulk of this literature may have been missed since electronic literature retrievals do not date back further than the 1960s. Mammalian studies consisted mostly of laboratory studies done on rats, although some information was available for mice, rabbits, and other species. Available aquatic toxicity data for boron are limited. For aquatic species, the literature was composed primarily of freshwater laboratory studies. Fish, herptile, and invertebrate information was limited or lacking. The published scientific "white" literature was reviewed adequately, but the scientific "gray" literature, which includes government reports and unpublished data, was not.

Abiotic Factors Affecting Bioavailability

Water

The predominant species of boron in most freshwater systems (pH<9) is undissociated boric acid (Hem 1970; Maier and Knight 1991); the chemical form of boron found in water is dictated by pH and other constituents (Sprague 1972). Boron compounds are water soluble and tend to accumulate in aquatic ecosystems (EPA 1975).

Soil

In the United States, soil usually contains around 30 mg B/kg, dry weight (dw) (range 10–300 mg/kg). The precipitation:evaporation ratio of an area is a key factor in determining the degree to which boron can concentrate in soils and reach toxic levels (Butterwick et al. 1989). The total boron content of soil is of little value for diagnosing boron status; experi-mental work by Gupta (1968) suggests that less than 5 percent of the soil boron is avail-able for plant uptake (Butterwick et al. 1989).

In soils, boron may be found in four forms: organically bound, water-soluble, adsorbed, and fixed in clay and mineral lattices (Adriano 1986). Arid, saline soils generally contain the highest boron concentrations. In sandy soils, boron is leached more readily than in clay soils and is thus less likely to accumulate to toxic concentrations (Adriano 1986). Boron can react and bind with clays, suspended matter, and sediments of aquatic systems. Boron adsorbed onto clays accounts for a major proportion of the boron in many aquatic systems (Maier and Knight 1991).

Biotic Effects

Plants

The environmental effects of boron are most noticeable in plants (Sprague 1972). Boron is an essential trace element for the growth and development of higher plants, for it plays important roles in the calcium cycle and in respiratory processes and the utilization of carbohydrates (Browning 1969). However, the range between insufficiency and excess is usually narrow. Gupta et al. (1985), for instance, found that some plants show signs of deficiency when boron concentrations in soil solution are <2 mg/L and show toxic effects at concentrations >5 mg/L. Other researchers report similarly narrow ranges of boron tolerance (Sprague 1972; Weir and Fisher 1972; Birge and Black 1977; Goldbach and Amberger 1986). The waterweed *Elodea canadensis* is sensitive to even very low ambient concentrations of boron; Perry et al. (1994) reported that it showed a reduced rate of photosynthesis in water containing 1 mg B/L (28-day exposure). In addition, *Hydrocotyle umbellata*, commonly found in the Southeastern United States, exhibited reduced growth and yellowing of the leaves when exposed to <1 mg B/L (Powell et al. 1997). A recent ecological risk assessment for a natural community of aquatic plants concluded that, at median spring and fall concentrations of 5.9 and 3.6 mg B/L, patterns of leaf tissue discoloration (yellowing) may indicate adverse ecological impacts on the vegetation (Powell et al. 1997).

Several factors affect plant uptake of boron, including soil texture, pH, macronutrients, temperature, light, evapotranspiration rate, and plant growth stage (Butterwick et al. 1989; Glandon and McNabb 1978). Frick (1985), for instance, found that a concentration of 20 mg B/L was sufficient to inhibit the growth of duckweed at pH 7.0 but that 100 mg B/L was required to produce the same effect at pH 5.0. Once boron is incorporated into plant tissues, it becomes relatively immobile. Leaves generally accumulate the greatest concentrations of boron in plants (Gupta et al. 1985).

Plant species do not all draw on the same boron supplies. Emergent plants absorb most of their boron from the hydrosoil; floating-leaf species absorb a large proportion of boron from sediments and water. Submerged plants, which lack or have greatly reduced root systems, obtain most of their boron from the water (Hutchinson 1975). Generally, floating-leaf species contain more boron than submerged or emergent plants, and dicotyledons usually contain more boron than monocotyledons (Boyd and Walley 1972; Cowgill 1974). In aquatic macrophytes, boron concentrations are usually less than 20 mg/kg dw. Based on samples from 22 species of aquatic macrophytes collected from natural environments, the mean tissue level of boron was 11.3 mg/kg dw (Powell et al. 1997). In green algae (Maeso et al. 1985) and blue-green algae (Martinez et al. 1986), adverse sublethal effects are apparent at boron concentrations of 50 mg/kg and higher.

Boron-contaminated irrigation water is one of the main causes of boron toxicity to plants. Evapotranspiration from irrigated fields concentrates boron in the soil and leads, eventually, to toxicity (Gupta et al. 1985). At some places in the Southwestern United States, naturally elevated boron concentrations in surface water used for irrigation are high enough to be toxic to plants of commercial importance (Benson et al. 1984). High concentrations of boron were found in aquatic plants growing in irrigation drain water at Kesterson Reservoir in the San Joaquin Valley of California. Widgeon grass contained 120–780 mg B/kg dw, and in one pond, Hothem and Ohlendorf (1989) found concentrations (1,630 mg/kg) high enough to impair avian reproduction if widgeon grass from that pond were a sole-source food supply. Widgeon grass seeds contained 430–3,500 mg B/kg dw (Schuler 1987) and algae contained 390–790 mg/kg (Hoffman et al. 1991) at Kesterson Reservoir. Levels of boron in plant tissues were elevated compared to mean concentrations found in water (20 mg/L) and sediment (20 mg/kg), indicating that boron was bioconcentrating in aquatic plants. Toxic effects of boron to various plant species, as reported in the literature, are summarized in table 7 at the end of this chapter.

Macroinvertebrates

Little information is available on the toxicity of boron to aquatic invertebrates (table 7). In tests with *Daphnia magna*, the no-observed-adverse-effect level (NOAEL) and the lowest-observed-adverse-effect level (LOAEL) were found to be about 6 and 13 mg B/L, respectively (Lewis and Valentine 1981; Gersich 1984). Hothem and Ohlendorf (1989) found that the boron concentration in adult damselflies was 27 percent lower than in nymphs. This result suggests that a greater proportion of boron in nymphs may be incorporated in the exoskeleton. Maier and Knight (1991) found a significantly decreased growth rate by *Chironomus decorus* larvae at boron concentrations of 20 mg B/L and greater. The concentrations of boron eliciting chronic sublethal responses in *C. decorus* are close to those reported in severely contaminated systems in the Central Valley of California (15–29 mg B/L).

Fish

The boron toxicity database for fish is relatively extensive, and several compre-hensive summaries have been compiled recently (e.g., SJVDP 1990; Perry et al. 1994). This literature, however, is mostly limited to evaluations of waterborne exposures to boron (i.e., without dietary exposure) and also does not include any definitive data relating boron levels in fish tissues to toxic effects. Con-sequently, although the database is extensive, its interpretive value is hampered by the critical gaps in "field-relevant" toxicity data (i.e., dietary exposures and tissue-based toxicity thresholds). Another confounding feature is the fact that threshold-level effects are commonly seen at water concentrations of boron much lower than the EC50 (see Appendix II for definition of terms), but EC50s and LC50s are the only standardized measures of toxicity consistently used in most bioassay-type toxicity studies. For sake of comparison, table 7 is largely restricted to summarizing EC50 and LC50 estimates of various studies. Toxicity measures based on various other endpoints are reported in SJVDP (1990) and Perry et al. (1994). The general concentrations of boron associated with threshold-level (e.g., EC1 to EC10) measures of toxicity will, however, be briefly summarized in discussions to follow.

The available literature indicates that boron levels of 0.001–0.1 mg/L could reduce the reproductive potential of sensitive fish species, and concentrations exceeding 0.2 mg/L could impair the survival of developmental stages for other species, under conditions providing continuous exposure from fertilization through 4 days posthatching (Birge and Black 1977). Birge and Black also found that boron compounds were more toxic to developmental and early posthatched stages than to adult fish. However, Hamilton and Buhl (1990) found no difference in the sensitivity of various life stages of fish exposed to boron for 96 hours. Both studies indicated that water hardness did not seem to affect boron toxicity (Birge and Black 1977; Hamilton and Buhl 1990).

The early life stages of rainbow trout appear to be the most sensitive to boron, with a consistent dose-response-related lowest observable effect concentration (LOEC) of 0.1 mg B/L (Birge and Black 1977). High boron concentrations (25–200 mg/L) were required to consistently produce substantial impairment to trout embryos and alevins.

High frequencies of both embryonic and postembryonic mortality in trout eggs were recorded only at boron concentrations of 50 mg/L or more. Embryonic mortality and teratogenesis were the principal boron-induced responses at 50 mg/L or less. Percent hatchability of trout eggs generally was inversely proportional to exposure level from 1 to 200 mg B/L (Birge and Black 1977). Borax at or below 0.5 mg B/L did not reduce hatching frequency; at 200 mg/L, hatchability dropped to zero. A high incidence of terato-genesis was observed over the range of exposure levels from 1.0 to 200 mg B/L. Borax and boric acid are unusual in that they exert low-level embryopathic effects on trout over a wide span of exposure levels (0.001–1.0 mg/L) (Birge and Black 1977).

In channel catfish, at a concentration of 200 mg B/L, normal survival at 4 days posthatching was only 0–2 percent; at 300 mg B/L, many of the eggs did not hatch, and those that did produced deformed hatchlings. Normal survival was 100 percent at and below 1.0 mg B/L. In both channel catfish and rainbow trout, embryonic mortality and teratogenesis increased in hard water, and boric acid produced higher frequencies than borax (Birge and Black 1977).

The low-level effects observed in reconstituted laboratory water, however, may not predict the much higher first effect levels under natural water conditions. Studies conducted for and by Procter and Gamble found that natural waters containing 0.75 mg B/L did not affect rainbow trout early life stages (Butterwick et al. 1989). Bingham (1982) was able to find at least some wild healthy trout in surface waters containing as much as 13 mg B/L, although it was not known how long those trout had been exposed nor whether they constituted a demographically healthy population. In demographically open populations, as was the case in Bingham's study, upstream and downstream movements can continually maintain the presence of fish even in a habitat where a closed population could not sustain itself. Thus, in such cases, data on the presence or absence of fish are of questionable value for delineating acceptable water quality characteristics.

Based on a limited number of field surveys, Saiki and May (1988) suggested that whole freshwater fish typically contain <4 mg B/kg. Results from laboratory and field studies suggest that boron bioaccumulation is common in fish, but bioconcentration is not (Perry et al. 1994; Ohlendorf et al. 1986; Saiki and May 1988; Hamilton and Wiedmeyer 1990; and Thompson et al. 1976).

Amphibians/Reptiles

Birge and Black (1977) found that leopard frog embryos suffered 100 percent lethality or teratogenesis in water treated with borax or boric acid at exposure levels of 200 or 300 mg B/L, respectively. Boron compounds are more toxic to embryos and larvae than to adult amphibians, and amphibians are more tolerant of boron than fish, particularly at low concentrations (Birge and Black 1977).

Birds

Toxic effects of boron in birds, as reported in the literature, are summarized in table 7 at the end of this chapter.

In mallards, adverse reproductive effects have been reported at dietary concentrations of 1,000 mg B/kg; hatching success of fertile eggs, body weights of ducklings at hatch, and survival of ducklings from hatching to day 7 were all substantially reduced when breeding adults and their offspring were maintained on a diet supplemented with 1,000 mg B/kg. Although the mallards had markedly impaired embryo survival, the teratogenic effects described in boron egg-injection studies were not observed in this study. Mallard embryo mortality was greatest during the second half of incubation, when energy demands for embryonic growth were great. Because no adults died as the result of dietary boron treatment, it appears that embryos and hatchlings are the most sensitive mallard life stages to boron toxicosis (Smith and Anders 1989).

Stanley et al. (1996) also found statistically significant adverse reproductive effects in mallards fed 900 mg B (as boric acid) per kilogram of dry feed. Hatching success was reduced to only 58 percent of controls, suggesting that this level of dietary exposure is close to the EC50 value. At a dietary exposure of 450 mg B/kg, hatching success was reduced to 88 percent of controls, suggesting an approximate EC10 value. Concentrations of boron in mallard eggs associated with these approximate EC50 and EC10 dietary exposures of hens were, respectively, 38 and 22 mg/kg dw.

Boric acid in the diet of ducklings hatched from untreated eggs proved to be less toxic than reported for ducklings hatched from boron-contaminated eggs. Hoffman et al. (1990) found 10 percent mortality at 10 weeks in ducklings from uncontaminated eggs that received 1,600 mg/kg dietary boron. Smith and Anders (1989) reported 21 percent mortality during the first week and 12 percent mortality during the second week in duck-lings that received 1,000 mg B/kg both from the adult hen mallard and in their own diet. In a natural setting, the ducklings would probably encounter both types of boron exposure, during embryogenesis and posthatching development, and so these higher mortality figures are probably more relevant.

Smith and Anders found that diets containing as little as 30 mg B/kg fresh weight (fw) fed to mallard adults adversely affected the growth rate of their ducklings. In a study by Hoffman et al. (1990), dietary levels of 100 mg B/kg fw resulted in reduced growth of female mallard ducklings. These findings indicate that concentrations greater than 30–100 mg B/kg in natural diets of ducklings could adversely affect their development.

Mallards fed concentrations up to 2,000 mg B/kg did not exhibit any histological pathologies. Therefore, histology may not prove to be an adequate means of assessing boron exposure or toxicosis in mallard ducks. Boron levels in egg, liver, and brain tissues increased in proportion to dietary concentrations of boron; however, these tissues contained residues that were at least one order of magnitude lower than the dietary concentration administered. Hoffman et al. (1990) and Smith and Anders (1989) found that boron accumulation in the brain and liver was substantially greater in all boron-supplemented groups than in controls, with a greater accumulation in the brain.

Pendleton et al. (1995) reported extremely rapid accumulation and elimination of boron in mallard tissues. Adult male mallards fed a diet containing 1,600 mg B/kg accumulated equilibrium levels of boron in liver tissue and blood within 2–15 days. After boron was removed from the diet of these mallards, it was completely cleansed from the liver and blood within 1 day. These findings are consistent with early research on cows and rats which revealed that the boron concen-tration of cow's milk could increase tenfold within the first 24 hours of dietary boron supplementation and that boric acid fed to rats is eliminated with extreme rapidity (Hove et al. 1939).

Mammals

The reported toxic effects of boron on mammals are summarized in table 7, at the end of this chapter. In general, excessive boron consumption by mammals results in a reduced growth rate and in some cases loss of body weight. Growth retardation has been reported in cattle given 150 mg B/L drinking water, in dogs consuming diets containing 1,750 mg B/kg, in rabbits eating rations equivalent to >140 mg B/kg bw daily, and in rats given 150 mg B/L in drinking water or 1,060 mg B/kg in food (Eisler 1990). In some instances, animals avoid boron-contaminated drinking water; rats reject drinking water containing as little as 1.0 mg B/L (Dixon et al. 1976), and cattle avoid water containing >29 mg B/L (Green and Weeth 1977).

Adverse effects on the reproduction of laboratory mammals have been reported in sensitive species fed diets containing more than 1,000 mg B/kg or given drinking water containing 1.0 mg B/L (Eisler 1990). Boric acid caused decreased fetal body weight and increased malformations in rats, mice, and rabbits with doses in the range of 80–400 mg/kg/day, given either throughout gestation or only during major organogenesis (Heindel et al. 1994).

Boron is readily transmitted into milk and eggs, as well as through the placenta (Hove et al. 1939). Boron compounds, especially boric acid, can accumulate in animal tissues and produce a reduction in fertility, an increase in developmental abnormalities, and death (Weir and Fisher 1972; Lee et al. 1978; Landolph 1985). Boron is found at concentra-tions ranging from 0.05–0.6 mg/kg fw in most animal tissues but may be several times higher in bones (Nielsen 1986). Mule deer metacarpals have been found to contain 0.8–3.6 mg B/kg dw, with younger animals having much higher bone boron concentra-tions than adults (Stetler 1980). Boron from boric acid has been shown to concentrate in the brain, spinal cord, and liver following ingestion (Beyer et al. 1983). Nontoxic concentrations of dietary boron (sodium borate or boric acid) are rapidly and almost completely absorbed from the gastrointestinal tract, do not seem to accumulate in healthy tissues, and are excreted in urine, usually within hours (NAS 1980; Benson et al. 1984; Nielsen 1986; Siegel and Wason 1986).

Bioaccumulation

Boron can be bioconcentrated to varying degrees by aquatic organisms (Ohlendorf et al. 1986). Green algae *(Chlorella pyrenoidosa*) had a bioconcentration factor of 5 (boron concentration five times the level in the surrounding medium) after being exposed to a 50–100 mg B/L boric acid solution for 7 days (Fernandez et al. 1984). In the San Joaquin Valley, filamentous algae accumulated 390–787 mg B/kg when exposed to brackish tile drainage containing 12–41 mg B/L, and they accumu-lated 64–140 mg/kg when exposed to fresher water containing 1.4–2.2 mg/L (Schuler 1987). Aquatic insects living in the tile drainage contained 22–340 mg B/kg, but those living in fresh water untainted by agricultural tile drainage contained 6–47 mg/ kg (Ohlendorf et al. 1986; Schuler 1987; Hothem and Ohlendorf 1989).

Lemna species are outstanding boron bioaccumulators. Proficiency in boron stripping coupled with a high growth rate distinguishes *Lemna minor* as an important species with respect to boron cycling in a freshwater macrophyte community. The effectiveness of this species in consuming boron may be a potent force in lowering the concentrations of this essential element in aquatic systems (Glandon and McNabb 1978). Frick (1985) determined that pH affected the bioaccumulation of boron in *Lemna minor*, indicating that chemical speciation of boron may affect bioaccumulation and toxicity.

Interactions

Hoffman et al. (1991) examined boron-selenium interaction effects in mallard ducklings under two very different conditions: (1) a protein-adequate diet and (2) an iso-caloric protein-deficient diet. Unquestionable interaction effects were noted only under conditions of protein deficiency. However, Hoffman et al.'s protein-deficient diet was unlike any likely to be encountered by ducklings in the wild, so the results for part 2 of their experiments are essentially irrelevant to these guidelines. The results of part 1 are more relevant to the real world and failed to reveal any substantive interaction effects (despite unrealistically high dosing levels). More recently, Stanley et al. (1996) experimentally studied the effects of boron-selenium interactions on mallard reproductive performance, duckling growth, and duckling survival. Their experiments also found little evidence of interaction between these elements.

Regulatory Standards

U.S. Environmental Protection Agency standards and criteria

[See Appendix II for explanation of terms. Source: EPA 1995]

Status	Listed for regulation; carcinogenicity unknown	
Drinking water MCL	Not established	
Drinking water health advisories for 10-kg child	1-day HA: 10-day HA: Long-term HA:	4 mg/L 0.9 mg/L 0.9 mg/L
Drinking water health advisories for 70-kg adult	Reference dose: Long-term HA: Lifetime HA: DWEL:	0.09 mg/kg/d 3 mg/L 0.6 mg/L 3 mg/L

For standards and criteria set by State agencies, contact those agencies directly. See Appendix I for a listing of water-quality officials in the 17 Western States.

Table 7.—Summary of literature for boron ecotoxicology

[LC50, median lethal concentration; LD50, median lethal dose; both indicate 50 percent mortality after a stated time interval. Similarly, LC100 denotes 100 percent mortality. dw, dry weight; bw, body weight; conc., concentration]

Species	Boron compound	Concentration	Test conditions	Effect	Reference
Plants					
Blue-green algae (*Anacystis nidulans*)	Boric acid	75–100 mg B/L	72 hours	Photosynthetic pigments depleted	Martinez et al. 1986; Mateo et al. 1987
Duckweed (*Lemna minor*)	Boric acid	100 mg B/L	pH 5.0	Growth inhibited	Frick 1985
		20 mg B/L	pH 7.0	Growth inhibited	
Waterweed (*Elodea canadensis*)	Boric acid	1 mg B/L	28 d	Reduced photosynthesis	Perry et al. 1994
Invertebrates					
Mosquito larvae (3 spp.)	Boric acid	700–2,797 mg B/L	Freshly hatched to pupae stages	LC100 (48 hr)	EPA 1975
Midge (*Chironomus decorus*)	Borax	1,376 mg B/L	Fourth instar	LC50 (48 hr)	Maier and Knight 1991
		20 mg B/L	Decrease in growth (96 hr)	Significant decrease in growth rate	
Water flea *(Daphnia magna)*	Boric acid	420 mg/L	Neonates	LC100 (48 hr)	Lewis and Valentine 1981; Gersich 1984
		115-246 mg/L	LC50 (48 hr)	LC50 (48 hr)	
		13–53 mg/L	Hard water	LC50 (21 d); reduced mean brood size and body length	
		13.6 mg/L	21 d	LOAEL, reproductive effects	
		6.4 mg/L	21 d	NOAEL	
Fish					
Bluegill (*Lepomis macrochirus*)	Boron trifluoride	15,000 mg B/L		LC50 (24 hr)	Birge and Black 1977
Chinook salmon	Boric acid	>1,000 mg/L	Eyed eggs, alevins and fry; soft water	LC50 (24 hr)	Hamilton and Buhl 1990
		566–725 mg/L	Fry; very hard and soft fresh water	LC50 (96 hr)	
Chinook and Coho salmon	Boric acid	>1,000 mg/L	Fry; very hard fresh and brackish water	LC50 (24 hr)	
Coho salmon	Boric acid	447 mg/L	Very hard fresh water	LC50 (96 hr)	

Table 7.—Summary of literature for boron ecotoxicology—Continued

Species	Boron compound	Concentration	Test conditions	Effect	Reference
Fish—Continued					
Channel catfish	Borax and boric acid	155 mg/L	Embryos and fry	LC50 (9 d)	Birge and Black 1977
Goldfish	Boric acid	75 mg/L	Embryos and fry; hard water	LC50 (7 d)	Birge and Black 1977
	Borax	59 mg/L			
Minnows	Boric acid	18,000–19,000 mg/L	Distilled water	Minimum lethal dose	EPA 1986
		19,000–19,500 mg/L	Hard water		
	Borax	19,000–19,500 mg/L	Distilled and hard water	Minimum lethal dose	Sprague 1972
	Anhydrous borax	3,000–7,000 mg/L			
	Boric acid	1,600–3,700 mg/L			
Mosquitofish (*Gambusia affinis*)	Boric acid	979 mg B/L	Adults	LC50 (96 hr)	Birge and Black 1977
Rainbow trout		339 mg/L	Adults	LC50 (48 hr)	Sprague 1972; Birge and Black 1977; Lewis and Valentine 1981
Amphibians					
Toad (*Bufo vulgaris*)	Boric acid	874 mg B/L	Embryos, 24-hr exposure	Edema, microcephalia, short tail, suppressed forebrain development	EPA 1975
Fowler's toad	Boric acid	145 mg/L	Embryos and tadpoles; soft water	LC50 (7.5 d)	Birge and Black 1977
		25–123 mg/L	Embryos and tadpoles; hard and soft water		
Leopard frog	Boric acid	130 mg/L	Embryos and tadpoles; soft water	LC50 (7.5 d)	Birge and Black 1977
	Borax	47–54 mg/L	Embryos and tadpoles; hard and soft water		

Table 7.—Summary of literature for boron ecotoxicology—Continued

Species	Boron compound	Concentration	Other conditions	Effect	Reference
Birds					
Domestic chicken	Boric acid (in food)	875 mg B/kg	Adult; 6-day exposure	Egg production ceased	Birge and Black 1977
Mallard duck (*Anas platyrhynchos*)	Boric acid (in food)	1,600 mg/kg dw	Ducklings; 10-week exposure	Reduced growth; increased resting time; duckling brain 51 mg/kg; liver 29 mg/kg dw	Hoffman et al. 1990; Stanley et al. 1996
		400 mg/kg dw		Delayed and reduced rate of growth among females; increased resting time in ducklings; adult brain 5 mg/kg dw, liver 3 mg/kg dw	
		100 mg/kg dw		Delayed and reduced rate of growth among females; reduced bathing time in ducklings; adult brain, 4 mg/kg dw, liver, 3 mg/kg dw	
		1,000 mg/kg dw	Hen dosed beginning 3 weeks prior to mating; ducklings dosed for 21 days after hatching	48% reduction in hatching success; reduced weight and survival of ducklings. Resulting B conc. (mg/kg dw): adult brain 41, liver 33; egg 49; duckling brain 66, liver 51	Smith and Anders 1989
		300 mg/kg dw		Reduced weight gain rate in ducklings. Resulting B conc. (mg/kg dw): adult brain 14, liver 15; egg 13; duckling brain 19, liver 17	
		30 mg/kg dw		Reduced weight and weight gain in ducklings through 21 days; egg, 3 mg/kg dw; duckling brain, 4 mg/kg dw	
Mallard duck (*Anas platyrhynchos*)	Boric acid (in food)	900 mg/kg dw		Reduced hen weight gain; reduced egg size, weight, and hatching success (by ~50% compared to controls)	Stanley et al. 1996
		450 mg/kg dw		Reduced egg hatching success (~10% compared to controls)	

Table 7.—Summary of literature for boron ecotoxicology—Continued

Species	Boron compound	Concentration	Test conditions	Effect	Reference
Mammals					
Dog (*Canis familiaris*)		1,170 mg B/kg	38 weeks exposure	Testicular degeneration; spermatogenesis cessation	Nielsen 1986; Weir and Fisher 1972
Rabbit (*Oryctolagus* sp.)	Borates (in food)	800–1,000 mg/kg bw	4-day exposure	Growth retardation	Anonymous 1983
Rat (*Rattus* sp.)	Boric acid (in food)	1,750 mg B/kg	25 days exposure	50% reduction in growth rate	Seal and Weeth 1980
	Boric acid (in food)	1,170 mg B/kg	2 years exposure	Sterility in males and females	Sprague 1972; Weir and Fisher 1972
	Sodium borate (in food)	1,060 mg/kg	Chronic exposure	Growth retardation; testicular atrophy	Anonymous 1983
	Boric acid	710–550 mg B/kg bw	Oral, single dose	LD50	Weir and Fisher 1972; EPA 1975; Dani et al. 1971
	Boric acid (in drinking water)	0.05 mg B/ kg bw	Daily for 6 months	Decreased spermatozoid count and activity	Krasovskii et al. 1976
	Boric acid (in food)	0.015–0.3 mg B/kg bw	Daily for 6 months	Adverse changes in testes	Anonymous 1983

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