

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY
REGIONAL WATER QUALITY CONTROL BOARD
CENTRAL VALLEY REGION

San Joaquin River Basin Plan Amendment

**BORON:
A LITERATURE SUMMARY FOR
DEVELOPING WATER QUALITY OBJECTIVES**

DRAFT

27 January 1999

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BORON: A LITERATURE SUMMARY FOR DEVELOPING WATER QUALITY OBJECTIVES

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INTRODUCTION

This report summarizes toxicological and water quality publications related to setting water quality objectives for boron. It was prepared as part of a Basin Planning project described in the *Work Plan for the San Joaquin River Basin Plan Amendment Addressing Salinity and Boron* (CRWQCB, CVR, 1997). The information in this report and other technical reports, such as reports on beneficial uses and water management, will be used during the development of water quality objectives for boron. This report primarily draws upon water quality criteria documents and research summaries of boron toxicity and environmental impacts.

BORON IN THE ENVIRONMENT

Boron is a rare element that is widely distributed and bound to oxygen in nature. Boron is always found in the environment as inorganic borates because of its high affinity for oxygen (ECETOC, 1997). Its average concentration in the earth's crust is 0.001% (Mason and Moore, 1982; Perry and Suffet, 1994). Boron is not found in the elemental form in nature. It is normally found in mineral deposits as sodium borate (borax) or calcium borate (colemanite). Boron is found mostly in sedimentary deposits and sediments but is also found in metamorphic and igneous rocks. Its occurrence in sedimentary material is highly variable. Boron is generally in higher concentrations in marine deposits than in lacustrine and fluvial sediments (Perry and Suffet, 1994). Boron is in sea water at concentrations typically of 5 mg/L (ECETOC, 1997).

According to Butterwick *et al.* (1989) and summarized by Perry and Suffet (1994), boron has been found in surface waters across the United States. The highest concentrations were in the Lake Erie, Colorado basin and in the Western Gulf regions. Boron in the Lake Erie Basin ranged from 0.028 to 0.700 mg/L with a mean of 0.210 mg/L. Boron in the Colorado River Basin ranged from 0.011 to 1.80 mg/L with a mean of 0.179 mg/L, and boron in the Western Gulf of Mexico region ranged from 0.034 to 1.726 mg/L with a mean of 0.289 mg/L. Boron concentrations also tend to be higher in the western USA. where concentrations of 5 to 15 mg/L may be found because of weathering of boron-rich formations and deposits (ECETOC, 1997).

Certain locations in the world have higher boron concentrations due to naturally occurring geologic characteristics or man-made causes (ECETOC, 1997). The Loa River in the northern Chile, which is influenced by volcanic sediment of the Andes mountains, had concentrations between 4 and 26 mg/L. Geothermal activity in central Italy resulted in high boron concentrations of 22 to 20,200 mg/L in thermal springs. Concentrations downstream of a borate plant in Rio Arenales, Argentina had boron concentrations as high as 6.9 mg/L. An extraordinarily high level of boron of 72 to 80 mg/L in public water supplies were found in France at Cambronne - les - Clermont. These elevated concentrations were the result of an old industrial waste disposal site. Sewage water in Egypt

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contained 1.67 mg/L boron. Boron was as high as 2.5 mg/L in Germany. Crude sewage in the UK averaged 3.3 to 3.6 mg/L boron.

BORON IN THE CENTRAL VALLEY REGION

A Regional Board survey of selected streams in California (Westcot, *et al.*, 1990) was initiated to determine natural background concentrations of trace elements for use in a method recommended by the State Board for establishing water quality criteria. The goal of the survey was to determine natural background concentrations in streams believed to be free of agricultural drainage and urban and industrial discharges. The survey showed that boron occurs in streams throughout California and is generally the most abundant trace element in unpolluted water. The survey found a median total boron concentration of 0.08 mg/L in 177 California streams. Eighty percent of the streams sampled showed boron concentrations less than 1 mg/L. The highest total boron concentration in the study of 12.5 mg/L was found in Panoche Creek west of Interstate 5 in Fresno County. Panoche Creek is in the San Joaquin River watershed.

A preliminary study of streams draining the eastern slope of the Coast Range showed elevated natural concentrations of total boron (Westcot, *et al.*, 1991). Concentrations in 12 creeks draining into the San Joaquin River in Stanislaus County from Del Puerto Creek north had total median boron concentrations that ranged from 0.94 to 10 mg/L. In the southern most locations in Merced, Fresno and San Benito Counties, eight creeks south of Del Puerto Creek to and including Los Banos Creek had median boron concentrations that ranged from 0.28 to 4.5 mg/L. In southwestern Merced County and northwestern Fresno County, eight creeks including Salt Creek in the north to and including Panoche Silver Creek and Los Gatos Creek in the south had median boron concentrations that ranged from 0.78 to 25 mg/L. These west-side tributaries are generally abundant in boron.

Shelton and Miller (1991) reported boron concentrations from April 1987 to September 1988 for streams draining the western slopes of the Sierra Nevada into the San Joaquin River. These included the Stanislaus River at Ripon, Tuolumne River at Modesto, and Merced River near Stevenson. Total recoverable boron ranged from 0.020 to 0.080 mg/L in the Merced River, from 0.010 to 0.050 mg/L in the Tuolumne River, and from less than 0.010 to 0.030 mg/L in the Stanislaus River. The tributaries draining the Sierra Nevada are relatively low in boron compared to the west side drainages.

Total boron was sampled by Regional Board staff in the Grassland Watershed of Western Merced County. From October 1995 through September 1997, boron concentrations reached as high as 15 mg/L for Rice Drain at Mallard Road (Chilcott, *et al.*, 1998). Boron in the Delta Mendota water supply canal (mile post 100.85) in 1987 through 1992 typically was 0.2 mg/L, but reached 2.1 mg/L in May 1988 (USBR, 1992).

Figure 1 compares total boron concentrations collected by Regional Board Staff from February 1985 to November 1997 for a downstream site, Airport Way near Vernalis and a site approximately 30 miles upstream at Hills Ferry Road above the confluence of the Merced River. Boron concentrations were consistently higher at the upstream site. Total boron ranged from 0.09 to 5.0 mg/L for Hills Ferry Road and ranged from 0.01 to 1.2 mg/L for Airport Way.

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Figure 1a. Comparison of Boron Concentrations for the San Joaquin River at Hills Ferry Road and Airport Way; 2 May 1985 through 30 October 1991

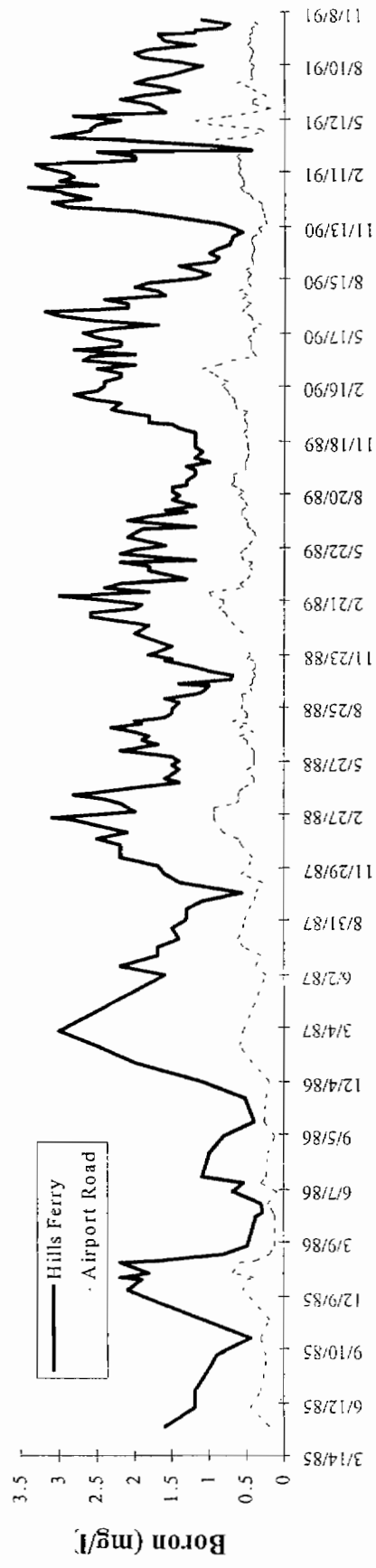
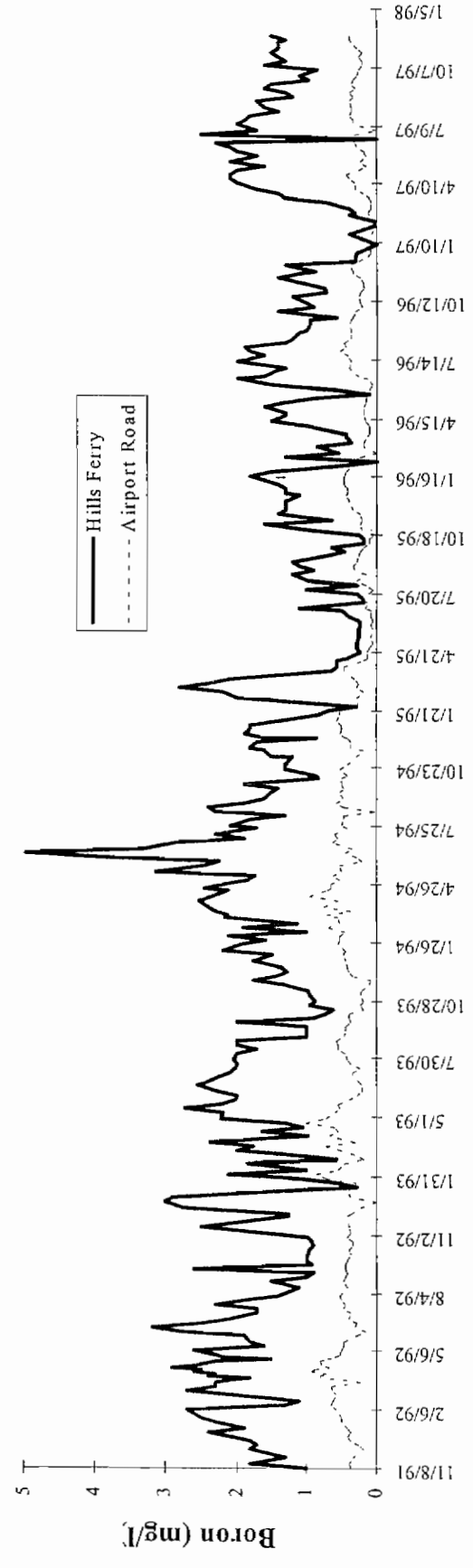


Figure 1b. Comparison of Boron Concentrations for the San Joaquin River at Hills Ferry Road and Airport Way; 1 November 1991 through 15 November 1997

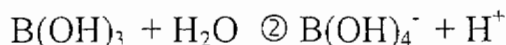


ENVIRONMENTAL CHEMISTRY OF BORON

Boron chemistry in fresh water approximates that observed in pure water. Its chemistry involves two species, the boric acid $B(OH)_3$ and borate or boric oxide (B_2O_3) ion. The equilibrium chemistry between the two compounds is:



Water (H_2O) drives the equation to the right. Boric acid is moderately soluble in water, and solubility increases substantially with increasing temperature (Perry and Suffet, 1994). Speciation varies with acidity according to the following equilibrium equation:



For basic conditions at a pH of approximately 8, which is characteristic of most natural waters including the Lower San Joaquin River, the concentration of $B(OH)_3$ will be approximately 20 times greater than $B(OH)_4^-$. Boric acid accounts for approximately 95% and the borate ion is approximately 5% of the total dissolved boron in freshwater systems (Perry and Suffet, 1994). Boron chemistry in fresh water characteristic of most natural waters in the San Joaquin River basin involves two species, $B(OH)_3$ and $B(OH)_4^-$. Both compounds adsorb on clays and oxide surfaces (Keren and Bingham, 1985).

Soils on the average have a higher boron content than rocks (Klasing & Pilch, 1988; Norrish, 1975). Boron exists in several forms in the soil (Eisler, 1990; Gupta and Macleod, 1982). Boron is mostly in a nonionic form or anionic form in soil. The predominant forms of boron in soil solutions with pH greater than 7 are $B(OH)_3$ and $B(OH)_4^-$ (Keren and Bingham, 1984). However, it is a trivalent cation (B^{3+}) at pH less than 7 where $B(OH)_3$ dominates.

The behavior of boron in natural waters and soils is complicated by the presence of other constituents. Interactions with commonly dissolved salts and minor elements can sometimes make the relationship between laboratory and field results confusing. For example, the boron tolerance of many plant species likely is enhanced by increasing levels of soil salinity (Ferreya, *et al.*, 1997).

IMPACTS IN WATER BY BENEFICIAL USE

A number of reports summarize the toxicity of boron. R.W. Sprague published in 1972 *The Ecological Significance of Boron* while working as a chemist for the U.S. Borax Research Corporation. He summarized the effects of boron on non-plant and plant life forms. Butterwick, *et al.*, (1989) did an assessment of boron in aquatic and terrestrial environments, and Klasing and Pilch (1988) looked at public health aspects of boron from agricultural drainage water contamination in the San Joaquin Valley. Eisler (1990), as part of U.S. Fish and Wildlife Service Contaminant Hazard Review Series, did a synoptic review of boron hazards to fish, wildlife and invertebrates. The San Joaquin Valley Drainage Program (1990) summarized the literature on the biological toxicity of a number of agricultural drainage chemicals including boron. Perry and Suffet (1994) did a report for the Regional Board on boron in aquatic systems. ECETOC (1997) summarized the ecotoxicology of some inorganic borates from particularly the U.S.A. and European literature.

The impact of boron on crops, human health, cattle, aquatic birds, fish and amphibians and other aquatic life are summarized in this report.

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Crop Use

Boron in relatively small quantities is essential for the growth of higher plants. However, it is toxic in slightly greater amounts. Boron toxicity in plants is characterized by leaf malformation (such as, leaf cupping in young grape leaves), chlorotic and necrotic patterns within leaves, although some sensitive fruit crops (such as stone and pome fruits) develop twig die-back and gummosis when exposed to toxic levels rather than exhibiting leaf injury (Maas, 1990).

In Table 1, crops are grouped according to tolerance to boron; the concentrations where plant damage occurs are shown in parentheses. In general, sensitive crops include citrus, stone fruits and nut trees. Semi-tolerant crops include cotton, tubers, cereals, grains, and olives. Tolerant crops include most vegetables (Eisler, 1990; Gupta, *et al.*, 1985). However, Oster (1997) has observed, that many tree and vine crops are less sensitive in the field than past classifications indicated, and other crop tolerances are likely conservative. Oster (1998) states that rainfall will reduce the average boron level in the soil, and if effective rainfall that reaches the root zone exceeds 8 inches per year based on long term averages, boron classifications could be increased by one level. ECETOC (1997) concluded that annual rainfall dilutes boron in soil thereby reducing the sensitivity of crops to boron in irrigation water.

Crop toxicity commonly occurs when boron in irrigation water concentrates in soils as a result of evapotranspiration. Soils have a large capacity for boron absorption, but toxicity may occur if that capacity is exceeded, which causes an increase in plant availability and boron uptake (Eisler, 1990; Gupta, *et al.*, 1985). Butterwick, *et al.*, (1989) summarized other factors that affect boron toxicity to higher terrestrial plants. A reduction in boron uptake by plants occurs with increasingly alkaline (higher pH) conditions. Increased nitrogen has in some cases decreased the severity of boron toxicity.

Cattle Use

Butterwick, *et al.*, (1989) summarized boric acid toxicity to cattle from two drinking water studies. In the first study, swelling and irritation of legs, lethargy and diarrhea occurred from 30 days exposure to boron acid at concentrations of 150 to 300 mg/L boron (Green and Weeth, 1977). In the other study, no signs of toxicosis were observed from exposure to 120 mg/L boron for 10 days (Weeth, *et al.*, 1981). Eisler (1990) proposed boron criteria for livestock drinking water of 5 mg/L as the maximum allowable, 40 mg/L as the maximum tolerated, 40-150 mg/L as “safe”, and over 150 mg/L as having adverse effects.

Boric acid at 2,000 mg/L in drinking water was detrimental to the growth of animals (Browning, 1961). Nielsen (1986) concluded that livestock showed signs of adverse effects from boron in drinking water at concentrations over 150 mg/L. Ayers and Westcot (1985) provided a guideline of 5 mg/L for livestock drinking water.

Table 1. Relative Boron Tolerance Of Agricultural Crops

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(Maas, 1990; Francois, 1991 and 1992)

Very Sensitive (<0.5 mg/L)*

Lemon	<i>Citrus limon</i>
Blackberry	<i>Rubus spp.</i>

Potato	<i>Solanum tuberosum</i>
Cucumber	<i>Cucumis sativus</i>
Lettuce	<i>Lactuca sativa</i>
Cherry	<i>Prunus avium</i>

Highly Sensitive (0.5-0.75 mg/L)

Avocado	<i>Persea americana</i>
Grapefruit	<i>Citrus X paradisi</i>
Orange	<i>Citrus sinensis</i>
Apricot	<i>Prunus armeniaca</i>
Peach	<i>Prunus persica</i>
Plum	<i>Prunus domestica</i>
Persimmon	<i>Diospyros khaki</i>
Cabbage	<i>Brassica oleracea capitata</i>
Fig, kadota	<i>ficus carica</i>
Grape	<i>Vitis vinifera</i>
Walnut	<i>Juglans regia</i>

Moderately Tolerant (2.0-4.0 mg/L)

Cowpea	<i>Vigna unguiculata (L.)</i>
Walp	
Turnip	<i>Brassica rapa</i>
Bluegrass, Kentucky	<i>Poa prtensis</i>
Pecan	<i>Carya illinoiensis</i>
Oats	<i>Avena sativa</i>
Maize/corn	<i>Zea mays</i>
Artichoke	<i>Cynara scolymus</i>
Tobacco	<i>Nicotiana tabacum</i>
Mustard	<i>Brassica juncea</i>
Clover, sweet	<i>Melilotus indica</i>
Squash	<i>Cucurbita pepo</i>
Muskmelon	<i>Cucumis melo</i>

Sensitive (0.75-1.0 mg/L)

Sweet potato	<i>Ipomoea batatas</i>
Wheat	<i>Triticum eastivum</i>
Sunflower	<i>Helianthus annuus</i>
Bean, mung	<i>Vigna radiata</i>
Sesame	<i>Sesamun indicum</i>
Lupine	<i>Lupinus hartwegii</i>
Strawberry	<i>Fragaria spp</i>
Artichoke, Jerusalem	<i>Helianthus tuberosus</i>
Bean, kidney	<i>Phaseolus vulgaris</i>
Bean, lima	<i>Phaseolus lunatus</i>
Peanut	<i>Arachis hypogaea</i>

Tolerant (4.0-6.0 mg/L)

Tomato	<i>Lycopersicon</i>
Alfalfa	<i>Medicagom sativa</i>
Vetch, purple	<i>Vicia benghalensis</i>
Parsley	<i>Petroselinum crispum</i>
Beet, red	<i>Beta vulgaris</i>
Sugar beet	<i>Beta vulgaris</i>
Cauliflower	<i>B. Oleracea botrytis</i>
Garlic	<i>Allium sativum lycopersicum</i>

Moderately Sensitive (1.0 - 2.0 mg/L)

Broccoli	<i>Brassica Olerace abotrytis</i>
Bean, snap	<i>P. vulgaris</i>
Pepper, red	<i>Capsicum annum</i>
Pea	<i>Pisum sativa</i>
Carrot	<i>Daucus carot</i>
Radish	<i>Raphanus sativus</i>

Very Tolerant (6.0-15.0 mg/L)

Sorghum	<i>Sorghum bicolor</i>
Cotton	<i>Gossypium hirsutum</i>
Asparagus	<i>Asparagus officinalis</i>
Celery	<i>Apium graveolens</i>
Onion	<i>Allium cepa</i>

NOTE: * Classification for tree and vine crops are based on leaf damage of young seedlings. Experience in California indicates extrapolation from leaf damage to yield reduction may not be appropriate (Oster, 1997). Cropping experience in California indicates the classifications of citrus, avocados and grapes may be less sensitive than indicated.

Human Health Effects

Murry (1995) states that there were insufficient data to establish an essential nutritional need for boron. He cites Nielsen (1994) as suggesting that boron is a probable essential trace element for humans.

Klasing and Pilch (1988) stated that because of the lack of information regarding concentrations, forms and relative toxicity of dietary boron compounds, it was impossible at that time to determine the potential risk from exposure to boron in the human diet. They stated that some human and animal studies indicated adverse male reproductive effects from "very high levels" of dietary boron (e.g. 0.3 mg/kg of body weight for rats exposed over 6 months). However, they concluded that acute and/or chronic dose-response, which was shown to cause such effects, was conflicting. They stated that additional studies were particularly needed to determine chronic dose-response effects.

Murry (1995) did a human health risk assessment of boron in drinking water using a relative source concept. He summarized key animal toxicity studies and concluded that the rat was the most sensitive species. It had a no observed adverse effect level (NOAEL) of 9.6 mg boron/kg/day for developmental toxicity. A Reference Dose was calculated at 0.3 mg boron/kg/day based on dividing the NOAEL by an uncertainty factor of eight for intraspecies variation and by four for interspecies variation. The Reference Dose of 0.3 mg boron/kg/day resulted in a total acceptable daily intake of 18 mg boron/day based on an average weight of 60 kilograms for a woman of child bearing age. Based on an average diet of 1.5 mg boron/day when removed from the total acceptable daily intake of 18 mg boron/day resulted in an acceptable drinking water uptake of 16.5 mg boron/day. Based on a daily drinking water consumption of two liters/day, a person could drink water containing up to 8.25 mg/L boron. Murry concluded from his risk assessment that consuming water with up to 4 mg/L boron per day would not be expected to pose any developmental, reproductive, or other health risk to the public.

The US EPA IRIS human health risk assessment database has a calculated reference dose NOAEL of 8.8 mg boron/kg/day for testicular atrophy and spermatogenic arrest in a 2-year dog study (Morry, 1998). The US EPA NOAEL is lower based on the dog study than the NOAEL that Murry (1995) used based on the rat study. US EPA IRIS data indicate that the dog is more sensitive than the rat to boron compounds. Based on this study on dogs, the reference dose as a drinking water level was calculated to be 0.63 mg/L (Marshack, 1998). Carolyn Smallwood (1998) from USEPA Washington, D.C. states that Boron is being evaluated with other chemicals in their new IRIS process. The process involves examining substances simultaneously for all routes of exposure and health effects, cancerous or noncancerous.

Aquatic Bird Use

Perry and Suffet (1994) summarized laboratory studies that examined toxicity to mallard ducks, *Anas platyrhynchos*, the only wild bird species for which toxicity tests have been conducted. These studies focused on dietary concentrations of boron.

Smith and Anders (1989) reported exposure to 1,000 mg/kg dietary boron in breeding mallards caused an increase in embryo and hatching mortality. Embryo growth reduction was recorded when hens were exposed to 300 and 1,000 mg/kg dietary boron. Hatchling weight gain was reduced at concentrations as low as 30 mg/kg dietary boron. Hoffman, *et al.*, (1990) found a 10% mortality in

one day old mallard ducklings exposed to concentrations of 1,600 mg/kg boron and growth reductions at concentrations of 100, 400 and 1,600 mg/kg of boron.

According to Perry and Suffet (1994), only four laboratory studies have addressed boron bioaccumulation in aquatic bird tissues. Dietary boron at 1,600 mg/kg produced concentrations in brain and liver tissues that were 25 and 29 times, respectively greater than the concentrations found in the corresponding tissues of control animals. Significant boron bioaccumulation in liver and brain tissue was reported when dietary boron concentrations were between 100 and 1,600 mg/kg for 10 weeks.

Eisler (1990) reviewed the literature and noted that dietary concentrations of 300 to 400 mg boron/kg in feed (fresh weight) affected mallard growth, behavior and brain chemistry. Dietary boron levels of 100 mg/kg fresh weight reduced growth of female mallard ducklings (Hoffman, *et al.*, 1990). Dietary boron as low as 30 mg/kg fresh weight fed to mallard adults affected offspring growth rates (Smith and Anders, 1989).

According to Perry and Suffet (1994), adverse biological effects to birds from boron occurred at 30 to 900 mg/kg based on the research of Hoffman, *et al.*, (1990), Smith and Heinz (1990) and Smith and Anders (1989). Adverse effects included embryo mortality, reduced egg size, loss of weight, reduced weight gain, lower growth rates and behavior changes in mallard adults or ducklings. These results were for boron as boric acid with the duration of exposure varying from 21 days to 10 weeks.

Stanley, *et al.*, (1996) studied the effects of boron and selenium in diets on mallard reproduction and duckling growth and survival. Diet supplements of boron (as boric acid) at 0, 450 or 900 mg/kg were fed to 26 pairs of breeding mallards. Hatching success was affected at 900 mg/kg but not at 450 mg/kg. Since egg concentrations of boron in these groups were considerably higher than residues reported for eggs at contaminated sites in the Central Valley, they concluded that it seemed unlikely that boron would be a significant factor in reducing hatching success of ducks, even at highly-contaminated sites (such as in evaporation ponds). They also concluded that even though boron does not appear to be a severe threat to wild birds as selenium, high concentrations of boron cannot be considered harmless.

Pendleton, *et al.*, (1995) studied the accumulation and loss of arsenic and boron (as boric acid) in dietary concentrations, and concluded, concerning drain water, that the toxic effects of boron on waterfowl behavior, physiology, and reproduction would only be expected at locations where birds would be exposed to very high levels. Skorupa (1998) stated that some species of aquatic birds, such as American coots and redhead ducks, feed largely on aquatic plants. He indicated that water concentrations of less than 8 mg/L may result in concentrations within aquatic invertebrates and plants that are high enough to adversely impact birds that feed upon these plants and organisms.

Fish and Amphibian Use

According to Sprague's (1972) reference to Wurtz (1945), rainbow trout and rudd were not affected in a 30-minute test with 350 mg/L boron as boric acid. The 48-hour lethal concentration where 50% mortality occurred (LC₅₀) for a 15 month-old rainbow trout was 339 mg/L boron in water. EPA (1972) states that Wurtz (1945) found in his study that 5,000 mg/L caused discoloration of the skin on trout.

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EPA (1972) summarized Wallen, *et al.*, (1957) as having established a 96-hour lethal concentration where 50% mortality occurs (LC₅₀) on mosquito fish (*Gambusia affinis*) at 5,600 mg/L for boric acid. EPA (1972) also stated that boric acid and borate would be expected to be less toxic to marine aquatic life than to freshwater organisms.

Birge and Black (1977) examined boron toxicity in the early life (embryo) stages of rainbow trout (*Oncorhynchus mykiss*), channel catfish (*Ictalurus punctatus*), goldfish (*Carassius auratus*), leopard frog (*Rana pipiens*) and Fowler's toad (*Bufo fowleri*). Fetal malformations were found including dwarf bodies and malformations of the cranium, vertebral column, fins, nervous system, yolk sac, and abdomen. Birge and Black (1977) showed aquatic concentrations at which 1% mortality (LC₁) and 50% mortality (LC₅₀) occurred in mg/L boron as follows:

<u>Aquatic Species</u>	<u>LC₁</u>	<u>LC₅₀</u>
trout	0.001 to 0.1 mg/L	27 to 100 mg/L
goldfish	0.2 to 1.4	46 to 75
catfish	0.2 to 5.5	22 to 155
amphibians	3 to 25	47 to 145

LC₅₀ values were significantly higher than LC₁ values for all species, particularly trout. These results were recorded at 4 days past hatching. Birge and Black (1977) compared their results with the literature and concluded that boron compounds were more toxic to developmental and early post-hatched stages than to adult fish. They also concluded from an analysis of variance that boric acid was significantly more toxic than borax to fish embryos. Hardness of water did not exert a statistically significant effect on boron toxicity, but a trend showed toxicity to embryonic stages generally was greater in hard water. In general, they state that boron concentrations of 100 to 300 mg/L were lethal for all species tested. LC₁ mortality could be the result of natural variability.

Black, *et al.*, (1993) published rainbow trout studies and concluded that the lowest observed effect concentrations (LOECs) were related to the effects of different types of dilution waters and the sensitivity of trout strains. From results of their laboratory tests on rainbow trout and their field surveys of streams that support viable trout, they concluded that 0.75 to 1.0 mg/L boron represented reasonable, environmentally acceptable limits for boron in aquatic systems.

The ECETOC report on boron (1997) states that rainbow trout (*Oncorhynchus mykiss*) and zebra fish (*Brachydanio rerio*) are the most sensitive fish species. Rainbow trout embryo-larvae stages are particularly sensitive having a no-effect threshold of approximately 1 mg/L boron. They suggest that the NOEC would likely be around 1 mg/L. They also cited a survey (via personal communications) of 37 fisheries biologists of boron concentrations of selected Western USA water bodies. Boron concentrations for creeks in this survey ranged from 0.05 to 5.0 mg/L with means ranging from 0.575 to 1.465 mg/L. None of these locations were limited by boron. Several locations in seven Western States with boron concentrations near or above long/L had viable trout populations (EA, 1994).

Adult rainbow trout recovered when placed in boron-free water after being exposed to 14,000 mg/L boron for 30 minutes (Perry and Suffet, 1994). The National Academy of Sciences (1973) water quality criteria document references a minimum lethal concentration (the lowest concentration where mortality occurs) at 3,145 to 3,407 mg/L boron as boric acid for minnows exposed for 6 hours. For adult female western mosquito fish (*Gambusia affinis*), the concentration needed to produce mortality decreased as exposure duration increased as follows:

<u>Exposure Duration</u>	<u>Boron Concentration (mg/L)</u>
1 day	1,360
2 day	929
4 day	408
6 day	215

Coho salmon (*Oncorhynchus kisutch*) under-yearlings, as reported by Thompson, *et al.*, (1976), when exposed for 12 to 23 days showed an LC₅₀ of 113 mg/L of boron. Chinook salmon (*Oncorhynchus tshawytscha*) as “swim-ups” and advanced fry had a 4-day LC₅₀ of 725 mg/L as reported by Hamilton and Buhl (1990). They also reported Coho salmon as “swim-ups” and advanced fry had a 4-day LC₅₀ of 447 mg/L boron.

Hamilton and Wiedmeyer (1990) found no boron detected in fish when exposed to concentrations as high as 6 mg/L. Using water from a Westlands Water District sump with boron concentrations ranging from 44 to 53 mg/L, Saiki, *et al.*, (1992) studied the toxicity of San Joaquin Valley water to juvenile chinook salmon (*Oncorhynchus tshawytscha*) and striped bass (*Morone saxatilis*). The primary objective of their study was to determine the effects of agricultural subsurface drainage on juvenile life stages of anadromous fish during long-term (28 days) exposure to drain water. They found chinook salmon and striped bass exposed to the drain water accumulated high concentrations of boron as high as 200 µg/g boron on a dry weight basis. They concluded that elevated concentrations of trace elements (especially boron and selenium) may have contributed to the toxicity of the drainage water, but the extent was not clearly defined. Hamilton and Buhl (1990) found boron as relatively non-toxic (96-hr, LC 50 > 100 mg/L) to swim-up and advanced fry stages of chinook salmon. Saiki, *et al.*, (1992) recommended implementing a monitoring program that includes on-site toxicity tests for sections of the San Joaquin River that receive drain water.

Saiki, *et al.*, (1993) concluded from sampling boron in aquatic food chains in the Lower San Joaquin River watershed that concentrations of boron (as well as molybdenum) were not biomagnified in the aquatic food chain, because concentrations were usually higher in filamentous algae and detritus than in invertebrates and fishes.

Hamilton (1995) conducted acute toxicity tests on three life stages of Colorado squawfish (*Ptychocheilus lucius*), razorback sucker (*Xyrauchen texanus*), and bonytail (*Gila elegans*) in a reconstituted water quality that simulated the Green River of Utah. He conducted tests with boron, lithium, selenate, selenite, uranium, vanadium, and zinc. Boron was ranked as the least toxic of these chemicals to three life stages (swim-up and two juvenile) of these fish species. Acute toxicity for boron at the 96-hour LC₅₀ ranged from greater than 100 to 527 mg/L.

Other Aquatic Life Use

Stanley (1974), as cited in Butterwick, *et al.*, (1989), observed that a concentration of 40.3 mg/L boron lead to a 50 percent inhibition of root growth in the freshwater plant *Myriophyllum spicatum* after 32 days of treatment. Glandon and McNabb (1978) observed no adverse effects on duckweed (*Lemna minor*) growth at exposures of 0.01, 0.11 and 1.01 mg/L boron. European Centre for Ecotoxicology and Toxicology of Chemicals (ECETOC), 1997 cited a study in Germany that showed the reed (*Phragmites australis*) water plant can tolerate relatively high boron concentrations of up to 4 mg/L for two years and up to 8 mg/L for 2-3 months. Reeds are particularly important for fish habitat.

006998

Another duckweed study by Frick (1985) indicated that normal growth occurred at boron concentrations of 10 and 20 mg/L. A boron concentration of 200 mg/L produced signs of toxicity in duckweed after 3 days and caused a decrease in growth after 6 days of exposure. Reduction in photosynthesis was observed in duckweed at 1 mg/L, based on an exposure of 28 days (Noble, 1981). Wang (1986) noted a 96 hours LC₅₀ of 60 mg/L boron for duckweed.

Perry and Suffet (1994) evaluated boron toxicity for a number of algae species as reported by other researchers. They reported that Bowen and Gauch (1966) observed a reduction in growth rate for the green algae (*Chlorella vulgaris*) at a boron concentration of 50 mg/L and a reduction in *C. prothioides* and *C. emersanii* growth at a boron concentration of 100 mg/L. McBride, *et al.*, (1971) reported the number and weight of *C. vulgaris* cells were neither stimulated nor inhibited by 0.5 mg/L and 10 mg/L boron. As indicated by their research and substantiated by previous findings by Gerloff (1968), boron does not seem to be required by green algae for growth.

Martinez, *et al.*, (1986) reported that boric acid concentrations of 10, 25 and 50 mg/L did not affect the growth rate or chlorophyll and protein contents in blue green algae (*Anacystis nidulans*) over a 96-hour exposure. However, higher concentrations of boron at 75 and 100 mg/L resulted in a decrease in growth rate and chlorophyll content. At 50, 75, and 100 mg/L of boron, they reported a reduction in growth and a drop in proteins, chlorophyll, and phycobiliproteins in the blue green algae species, *Anabaena* PCC 7119. Phytoplankton can tolerate up to 10 mg/L inorganic boron in the absence of other stresses (Antia and Cheng, 1975; Eisler, 1990).

According to Eisler (1990), no observable effect concentrations were seen at a boron concentration (as a boric acid) of 13.6 mg/L for freshwater invertebrates (Cladoceran, *Daphnia magna*) and at 37 mg/L for marine biota (sea urchin, *Anthocardaris crassispina*). Bringmann (1978) noted that cell replication in the fresh water protozoan (*Entosiphon sulcatum*) was reduced by 5 percent when exposed to 1 mg/L boron for 3 days. Kapu and Schaeffer (1991) examined behavior responses in the flatworm planarian (*Dugesia dorocephala*) after exposure to various concentrations of metals including boron at 1 to 60 minute intervals. Effects on behavior -- mostly restlessness, hyperkinesia, spiraling and reed/nose twist -- were observed at 1 mg/L boron. Data from European invertebrate test showed that chronic toxicity for borate is above 6 mg/L (ECETOC, 1997).

A few studies focused on the determination of acute and chronic lethal and sublethal effects of boron on the water flea (*Daphnia magna*). No observable effect concentration (NOEC) and lowest observable effect concentration (LOEC) values for this species were calculated at 6 and 13 mg/L boron (Butterwick, *et al.*, 1989). Studies by Lewis and Valentine (1981) and Gersich (1984) on *Daphnia magna* reported 48-hour LC₅₀ values of 226 and 133 mg/L and 21-day LC₅₀ values of 53.2 and 52.2 mg/L, respectively.

Maier and Knight (1991) found lethal and sublethal toxicity for water flea (*Daphnia magna*) and benthic invertebrate midge (*Chironomus decorus*) when exposed to tetraborate. The 48-hour LC₅₀ for the water flea (*Daphnia magna*) was 141 mg/L. The 48-hour LC₅₀ for *C. decorus* was 1,376 mg/L. A 48-hour exposure to a boron concentration of 20 mg/L resulted in a significant decrease in midge larval growth rate.

Preliminary investigations by USEPA (1975) showed a 48-hour LC₅₀ boron concentration of 700, 1,748 and 2,797 mg/L for four stages of development for the most sensitive species of mosquito larvae. The sea urchin (*Anthocidaris crassispina*) had 100% mortality when exposed to 75 mg/L boron, but had normal development at 37 mg/L boron according to Kobayashi (1971). Juvenile Pacific oysters (*Crassostrea gigas*) accumulated boron in relation to availability but showed no prolonged retention of boron after exposure ceased (Thompson *et al.* 1976; Eisler, 1990). Butterwick, *et al.* (1989) after summarizing toxicity data for amphibians, invertebrates, algae and other aquatic life stated that no evidence has been found that aquatic organisms bioaccumulate boron. Perry and Suffet (1994) state that additional laboratory studies of boron uptake and bioaccumulation are needed to gain a better understanding of these mechanisms in aquatic invertebrates.

007000

WATER QUALITY CRITERIA FOR BORON

Water quality criteria has been published by US EPA and others. National and generalized values for boron have been published. However, site-specific objectives will need to be set for the Lower San Joaquin River. The Lower San Joaquin River has been defined as that section the River from Mendota Dam to Airport Way Bridge near Vernalis. This section will summarize the criteria, goals and reference numbers as found in the literature and from conversations with experts. Data gaps are also discussed.

No California or Federal drinking water standards have been established for boron. Based on a 2 year dog study for testicular atrophy and spermatogenic arrest, US EPA published their NOAEL boron reference dose for chronic oral exposure in their Integrated Risk Information Systems (IRIS) database in June 1995. The NOAEL for this study was 8.8 mg/kg/day and the Reference Dose (RfD) was 0.09 mg/kg/day. The resulting lifetime health advisory level for boron was 0.63 mg/L. US EPA rounded this number down to 0.600 mg/L, and published it as a Suggested No-Adverse-Response Level (SNARL) for toxicity other than cancer. In addition, a state action level of 1.0 mg/L was published by the California Department of Health Services (Marshack, 1998). The Chilean boron standard in water used for human consumption is 4 mg/L, which is a reflection of high natural levels in fresh water in northern Chile (ECETOC, 1997).

US EPA (1986) has an agricultural water quality criterion for boron at 0.75 mg/L to protect sensitive crops during long-term irrigation (Marshack, 1995). Ayers and Westcot (1985) recommended a concentration of 0.7 mg/L boron in water that would require no restriction for agricultural use.

Agricultural criteria may sufficiently protect aquatic life, but evaluation of water quality impact on aquatic life is needed to determine if it does. Boron standards have not been set by either the US EPA National Ambient Water Quality Criteria, California Ocean Plan or US EPA National Ambient Water Quality Criteria for the protection for aquatic life.

The State Water Resources Control Board Technical Committee 1987 final report (SWRCB, 1987, p. IV-8) recommended a continuous criterion for agricultural of 0.5 mg/L. They concluded that aquatic toxicity data for boron was sparse. Using LC₅₀ data, which they stated did not provide an accurate estimate of a no effect level, they estimated a lowest adverse effect level of 5.8 mg/L as the less than ideal estimate of chronic toxicity based on the three most sensitive species in Table 2 (rainbow trout, channel catfish and the water flea, *daphnia magna*).

The estimated lowest effect level was also based a national average boron concentration of 0.1 mg/L. They recommended a continuous water quality criterion of 0.760 mg/L and an instantaneous maximum criterion of 5.8 mg/L for boron.

Because aquatic life standards have not been developed on a national or statewide basis for boron, aquatic toxicity has been reviewed as background for setting objectives for the Lower San Joaquin River. For toxic chemicals, the four basic methods that have identified as potential approaches for developing criteria are the US EPA's National Guidelines Tier I method, the Tier I method as modified by the California Department of Fish and Game, the US EPA's Tier II (Great Lakes) method and the State Water Resources Control Board Ocean Plan method with modifications.

007001

In 1988 a modified ocean plan method was used by the SWRCB Technical Committee to derive specific criteria for agricultural drainage (SWRCB, 1988). Table 2 provides a listing of the adverse effects of boron on aquatic organisms, in order of increasing concentration, from the SWRCB Technical Committee report as supplemented with additional information that has been summarized in this report. Rainbow trout embryo/larvae are the most sensitive of the fish species listed. However, they have an LC₁₀ that varied widely from 1.02 to 79 mg/L for 28 days of exposure. Black, *et al.*, (1993) stated that only consistent concentration-response levels of boron toxicity should be considered in determining boron toxicity risk levels. Birge and Black (1977) state that high concentrations (25 to 200 mg/L) were required to consistently produce substantial impairment of tests populations. The water plant *Elodea canadensis* when exposed to 2.0 mg/L of boron for 28 days, had photosynthesis damage. The third most sensitive species on their list, the water flea *Daphnia magna*, had reduced reproduction when exposed to a boron concentration of 13.0 mg/L for 21 days.

007002

Table 2. Adverse Effects From Boron On Freshwater Aquatic Organisms

(modified from SWRCB, 1988)

<u>Species</u>	<u>Boron (mg/L)</u>	<u>Effect</u>	<u>Duration</u>	<u>Reference</u>
Rainbow trout embryo/larvae	1.02	LC ₁₀	28 Days	Birge, <i>et al.</i> , 1980
Water Plant <i>Elodea canadensis</i>)	2.0	Photosyn.	28 Days	Nobel, 1981
Water flea <i>Daphnia magna</i> (<24 hour)	13.0	Reprod.	21 Days	Lewis & Valentine, 1981
<i>Daphnia magna</i> (<24 hour)	13.6	Reprod.	21 Days	Gersich, 1984
Zebra Fish (Brachydanio rerio)	14.2	LC ₅₀	96 Hours	ECETOC, 1997
Channel catfish embryo/larvae	22.0	LC ₅₀	9 Days	Birge & Black, 1977
Rainbow trout embryo/larvae	27.0	LC ₅₀	28 Days	Birge & Black, 1977
<i>Myriophyllum spicatum</i>	40.3	Root growth	32 Days	Stanley, 1974
Goldfish embryo/larvae	46.0	LC ₅₀	7 Days	Birge & Black, 1977
Leopard frog embryo/larvae	47.0	LC ₅₀	7.5 Days	Birge & Black, 1977
Blue green algae <i>Anabaena</i> PCC 7119	50	Growth	96 Hours	Martinez, <i>et al.</i> , 1986
<i>Daphnia magna</i>	52.2	LC ₅₀	21 Days	Gerish, 1984
Rainbow trout embryo/larvae	54.0	LC ₅₀	28 Days	Birge & Black, 1977
Leopard frog embryo/larvae	54.0	LC ₅₀	7.5 Days	Birge & Black, 1977
Goldfish embryo/larvae	59.0	LC ₅₀	7 Days	Birge & Black, 1977
Lema minor duckweed	>60.0	LC ₅₀	96 Hours	Wang, 1986
Adult shrimp <i>Neomysis mercedis</i>	64.7	LC ₅₀	14 Days	Bailey & Joe, 1986
Goldfish	65.0	LC ₅₀		
Channel catfish embryo/larvae	71.0	LC ₅₀	9 Days	Birge & Black, 1977
Goldfish embryo/larvae	75.0	LC ₅₀	7 Days	Birge & Black, 1977
Blue green algae <i>Anacystis nidulans</i>	75	Growth	96 Hours	Martinez, <i>et al.</i> , 1986
Rainbow trout embryo/larvae	79.0	LC ₅₀	28 Days	Birge & Black, 1977
Coho Salmon under-yearlings	113	LC ₅₀	12 to 23 Days	Thompson, <i>et al.</i> , 1976
<i>Daphnia magna</i>	133	LC ₅₀	2 Days	Lewis & Valentine, 1981
<i>Daphnia magna</i>	141	LC ₅₀	2 Days	Maier & Knight, 1991
Duckweed <i>Lema minor</i>	200	Growth	3 Days	Frick, 1985
<i>Daphnia magna</i>	226	LC ₅₀	2 Days	Lewis & Valentine, 1981
Coho Salmon swim-ups	447	LC ₅₀	4 Days	Hamilton & Buhl, 1990
Chinook Salmon swim-ups	725	LC ₅₀	4 Days	Hamilton & Buhl, 1990
Benthic invertebrate midge	1,376	LC ₅₀	2 Days	Maier & Knight, 1991

007003

The Technical Committee Report on water quality criteria (SWRCB, 1988) concluded that aquatic toxicity data for boron was limited and did not allow a very high degree of confidence. However, they recommended a criterion of 0.55 mg/L, based on the log mean of 2.98 mg/L of the concentrations of the three most sensitive species on their list. Their calculation was based on adverse effects from boron concentrations of their three most sensitive species as follows:

1.02 mg/L LC₁₀ for rainbow trout (embryo/larva)

2.0 mg/L for *Elodea canadensis*

13.0 mg/L for *Daphnia magna*

They averaged the natural log means of these concentrations as follows:

$$\ln 1.02 = 0.019$$

$$\ln 2.0 = 0.693$$

$$\ln 13.0 = \underline{2.564}$$

$$\text{mean} = 1.092$$

Taking the anti-logarithm:

$$e^x \text{ of } 1.092 = 2.98 \text{ mg/L, the concentration that showed an effect.}$$

A natural ambient background concentration of 0.1 mg/L was used as the concentration that showed a no effect level. That concentration with the 2.98 mg/L effect level was used to determine the recommended criterion by averaging the natural logarithms as follows:

$$\ln 2.98 = 1.09$$

$$\ln 0.1 = \underline{-2.3}$$

$$\text{mean} = -0.605,$$

and taking the antilogarithm to determine the concentration:

$$e^x \text{ of } -0.605 = 0.55 \text{ mg/L.}$$

Based on this conservative ocean method that appears to have a built-in safety factor, a boron concentration of 0.55 mg/L was recommended as an interim criterion. Their number was based on an unusually low LC₁₀ of 1.02 mg/L for rainbow trout in Birge and Black (1981), and a national mean obtained from 1,546 lake and river water samples as an ambient background concentration of 0.1 mg/L was used to calculate the criterion. This national ambient background may or may not represent natural background concentrations for the Lower San Joaquin River. Varying the ambient background somewhat will affect the calculated criteria value. For example, ambient concentrations of 0.2 and 0.3 mg/L would result in a calculated boron criteria of 0.77 and 0.94 mg/L, respectively.

A University of California Committee of Consultants (1988), evaluated San Joaquin River water quality objectives for boron (along with selenium and molybdenum). Based on a limited data set and using the more protective Ocean Plan Method, they calculated a criteria of 0.5 mg/L for boron. This value was obtained by determining an adverse effect concentration of 2.08 mg/L for the most sensitive three species (rainbow trout, *Alate canadensis* and *Daphnia magna*). They recommended developing a larger data base on boron toxicity to aquatic plants, which are likely more sensitive to boron than animals.

007004

In 1990, the US EPA Criteria Branch in Washington D.C. began development of a draft water quality criteria document for boron. Criteria Branch Chief Robert April (1990) stated that the 1972 Water Quality Criteria value of 0.75 mg/L boron for crop irrigation would probably be under protective for aquatic life. He stated that a likely criteria value of 0.50 to 0.55 mg/L would represent an acceptable interim aquatic life criterion, and advised that this standard will also protect wildlife. He based this advice on their rough assessment of laboratory values and the low potential for boron to bioaccumulate in wildlife. However, their work with technical support has not been completed (Delos, 1997).

Black, *et al.*, (1993) in a more recent publication based on laboratory and field studies on rainbow trout, the most sensitive of the species as noted in the 1988 SWRCB report, recommended a concentration of 0.75 to 1.0 mg/L as a reasonable environmentally acceptable limit for boron in aquatic systems. They stated that the gradually sloping response curve determined by Birge & Black (1977) over a broad concentration range, complicated the determination of a precise no-effect and lowest value. A 0.50 to 0.55 mg/L criteria appears too low because of the lack of consistent survival data on embryo-larval stages of trout in soft water based on results of Birge and Black (1977) and based on more recent analysis by Black, *et al.*, 1993.

SUMMARY AND CONCLUSIONS FROM THE LITERATURE

Table 3 summarizes boron concentrations that affect crops, fish, amphibians, aquatic birds, freshwater plants, algae, invertebrates, livestock, and human health. Agricultural water quality goals range from 0.7 to 0.75 mg/L but certain crops, such as lemon and blackberry, are sensitive to boron concentrations of 0.5 mg/L or lower. Other crops, such as asparagus, can tolerate from 6.0 to 15.0 mg/L boron in irrigation water.

As seen in Table 3, effects for aquatic biology range widely. Amphibians seem to be the most tolerant of the aquatic organisms, whereas rainbow trout appear to be the most sensitive of the tested fish species. The ECETOC (1997) literature summary of the effects of boron in the environment states that data on aquatic organisms show that the embryo/larval stages of the rainbow trout are the most sensitive to borate. Birge and Black (1977) stated that high concentrations of boron (25-200 mg/L) were required to consistently produce substantial impairment of test populations. Black, *et al.*, (1993) state that a boron concentration between 0.75 and 1.0 mg/L is reasonable and environmentally acceptable limit for rainbow trout and Papachristou, *et al.*, (1987) recommended a criteria of 5 mg/L for fish. Skorupa (1998) indicated that water concentrations of less than 8 mg/L may result in concentrations within aquatic invertebrates and plants that are high enough to adversely impact birds that feed upon these plants and organisms.

Livestock seem to be comparatively tolerant to boron in drinking water with 5 mg/L being the proposed maximum allowable concentration. No California or Federal drinking water standards have been established for boron. However, as a reference, the California Department of Health Services has published a State Action Level of 1 mg/L, and US EPA Integrated Risk Information System (IRIS) has a Reference Dose of 0.63 mg/L for non-carcinogenic effects.

007005

Table 3. Summary Of Boron Effect Levels In Water

	<u>BORON</u> (mg/L)	<u>REFERENCE</u>
<u>Crops</u>		
Very Sensitive	<0.5	Mass, 1990; Francois, 1991 and 1992
Sensitive	0.5-1.0	
Moderately Sensitive	1.0-2.0	
Moderately Tolerant	2.0-4.0	
Tolerant	4.0-6.0	
Very Tolerant	6.0-15.0	
Irrigation Goals	0.7-0.75	Ayers & Westcot, 1985; USEPA, 1985
Irrigation Recommendation	1.0-1.2	Oster, 1997
<u>Fish and Amphibians</u>		
Rainbow Trout (larval/embryonic)	0.75-1.0	Black, <i>et al.</i> , 1993; ECETOC, 1997
Chinook Salmon 96-hr., LC ₅₀	>100	Hamilton & Buhl, 1990
Amphibians	25-200	Birge & Black, 1977
Channel Catfish, 9-day LC ₅₀	22	Birge & Black, 1977
Fish	5	Papachristou, <i>et al.</i> , 1987
<u>Aquatic Birds</u>		
Mallards Adverse Effects from 3 to 10 Weeks of Exposure to a Diet of Plants and Invertebrates Grown	<8-12	Skorupa, 1998
<u>Freshwater Plant</u>		
<i>Myriophyllum spicatum</i> , 32 days 50% Inhibited in Root Growth	30	Stanley, 1974
Reed, <i>Phragmites Australis</i>		ECETOC, 1997
2 year test	4	
2-3 month test	8	
Duckweed signs of Toxicity after 3 Days Decrease in Growth after 6 days	200	Frick, 1985
Aquatic Plants in General	4	Papachristou, <i>et al.</i> , 1987
Duckweed Reduction in Photosynthesis from 28 Days of Exposure	1	Nobel, 1981
<u>Algae</u>		
Green Algae (<i>Chlorella vulgaris</i>) Reduction in Growth	50	Bowen and Gauch, 1966
<i>C. Prothiocoides</i> and <i>C. Emersanii</i> Reduction in Growth	100	Bowen and Gauch, 1966
Blue Green (<i>Anacysis nidulans</i>) Decrease in Growth Rate Chlorophyll Content from 96-hr. exposure	75 and 100	Martinez, <i>et al.</i> , 1986

Table 3. Summary Of Boron Effect Levels In Water (Continued)

007606

	<u>BORON</u> (mg/L)	<u>REFERENCE</u>
<u>Algae</u> (continued)		
Protozoan (<i>Entosiphon sulcatum</i>) Cell Replication Reduced by 5% from 3 days Exposure	1	Bringmann, 1978
Flatworm planarian (<i>Dugesia dorotacephala</i>) Behavior Effects from 1 to 60 Minutes Exposure Interval	1	Kapu and Schaeffly, 1991
<u>Bacteria, Protozoa and Invertebrates</u>		
Water Flea (<i>Daphnia magna</i>) Reproductive effects after 24 hours	13	Lewis and Valentine, 1981, Gersich, 1984
two day LC ₅₀	133 and 226	Lewis and Valentine, 1981
21 day LC ₅₀	52 and 53	Lewis and Valentine, 1981
<i>Daphnia magna</i> two day LC ₅₀	141	Maier and Knight, 1991
Midge (<i>Chironomus decorus</i>) two day LC ₅₀	1,376	Maier and Knight, 1991
Mosquito Larvae two day LC ₅₀	700-2,797	US EPA, 1975
<u>Livestock Drinking Water</u>		
Guidelines for Livestock Drinking Water	5	Ayers & Westcot, 1985
Eisler (1990; table 10) was referenced as a source document for:		
Maximum Allowable	5	NAS (1980); Weeth, <i>et al.</i> , 1981; Green & Weeth, 1977
Maximum Tolerated "Safe"	40 40-150	Seal & Weeth, 1980 Green & Weeth, 1977
Adverse Effects	>150	Nielsen, 1986
<u>Human Health</u>		
US EPA Preliminary Investigation Considered Safe	1.0 <20	US EPA, 1975 Papachristou, <i>et al.</i> , 1987
State Action level	1.0	California DHS (Marshack, 1998)
Reference Dose as a Drinking Water Level	0.63	from US EPA IRIS Database (Marshack, 1998)
Risk Assessment	4	Murry, 1995
<u>Bacteria, Protozoa & Invertebrates</u>		
<i>Pseudomonas putida</i> LC ₁₀ chronic, 16 hr	7.6	ECETOC, 1997

Note: * US EPA is currently doing an IRIS review process for boron and other chemicals (Smallwood, 1998)

CONCLUSIONS FROM THE LITERATURE

007607

Results from Saiki, *et al.*, (1993) concluded that boron biomagnification does not occur in fish collected in the San Joaquin River. Their conclusion was based on boron concentrations in tissue of fish species that were greater than concentrations in the water, but generally lower than concentrations in aquatic plants and invertebrates. Saiki (1998) believed that existing information on the toxic effects of boron to aquatic organisms is too sparse to warrant more than interim water quality objectives for aquatic organisms in the San Joaquin Basin. He stated that only a few studies have examined sublethal effects of long-term exposure to dissolved boron and even fewer studies have examined the effects of dietary exposure. He stated that more studies are needed before objectives can be set that can confidently protect fish and wildlife resources.

Saiki (1998) has some concerns over the concentration of boron in algae and the possibility of their consumption by fish or wildlife. He states:

Available data suggests that concentrations of boron occurring in filamentous algae (as much as 280 µg B/g, dry weight basis) and particulate detritus (as much as 190 µg B/g, dry weight basis) from the San Joaquin River or its tributaries (see Saiki et al., 1993) could already be sufficiently elevated to elicit sublethal responses in biota. For example, Smith and Anders (1989) reported that dietary boron as low as 30 mg/kg fresh weight (about 150 mg/kg dry weight, assuming 80% moisture) fed to mallard adults affected offspring growth rates. Even though mallards do not forage on filamentous algae, there are other waterfowl that do rely upon algae as food (e.g. gadwall and perhaps coots) although it is unknown if these species are sensitive to boron toxicity.

Perry and Suffet (1994) analyzed data requirements for boron water quality criterion. They summarized the literature by stating that lethal effects of boron are apparent at concentrations that are often at least one order of magnitude higher than concentrations at which sublethal effects were observed. They recommended chronic lethal and sublethal boron toxicity tests on freshwater aquatic plants, aquatic invertebrates, fish, amphibians, and aquatic birds living in the San Joaquin Valley.

Perry & Suffet (1994) in their review of the literature recommended that a second priority for future boron studies after determining chronic lethal and sublethal effects is to evaluate the interaction between selenium and boron in aquatic organisms. They believe that a better data base needs to be developed before final objectives for boron can be set within the San Joaquin River system.

007008

Glossary

LC₁	The lethal concentration (LC) at which 1% of the test population dies.
LC₁₀	The lethal concentration at which 10% of the test population dies.
LC₅₀	The lethal concentration at which 50% of the test population dies.
LD₅₀	The lethal dose (LD) of a toxicant to 50% of the test population.
LOAEL	Lowest observed effect level is the lowest dose resulting in an adverse effect.
LOEC	Lowest observed effect level is the lowest concentration that causes an effect that is statistically significantly different from the controls.
MCL	Maximum contaminant level
MLD	Minimum lethal dose (MLD) is concentration required to kill one or more of the test species.
NOAEL	No observed adverse effect level is the highest dose resulting in no adverse effect.
NOEL	No observed effect level is the highest concentration that causes no effect that is statistically significant than the controls.

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