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

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Table of Contents

List of Tables

List of Figures

DRAFT

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INTRODUCTION

This report summarizes toxicological and water quality publications related to setting boron water quality objectives for the Lower San Joaquin River (Figure 1). 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 contained here will be used to evaluate water quality objectives for boron. This report primarily draws upon water quality criteria documents and research summaries of boron toxicity and environmental impacts.

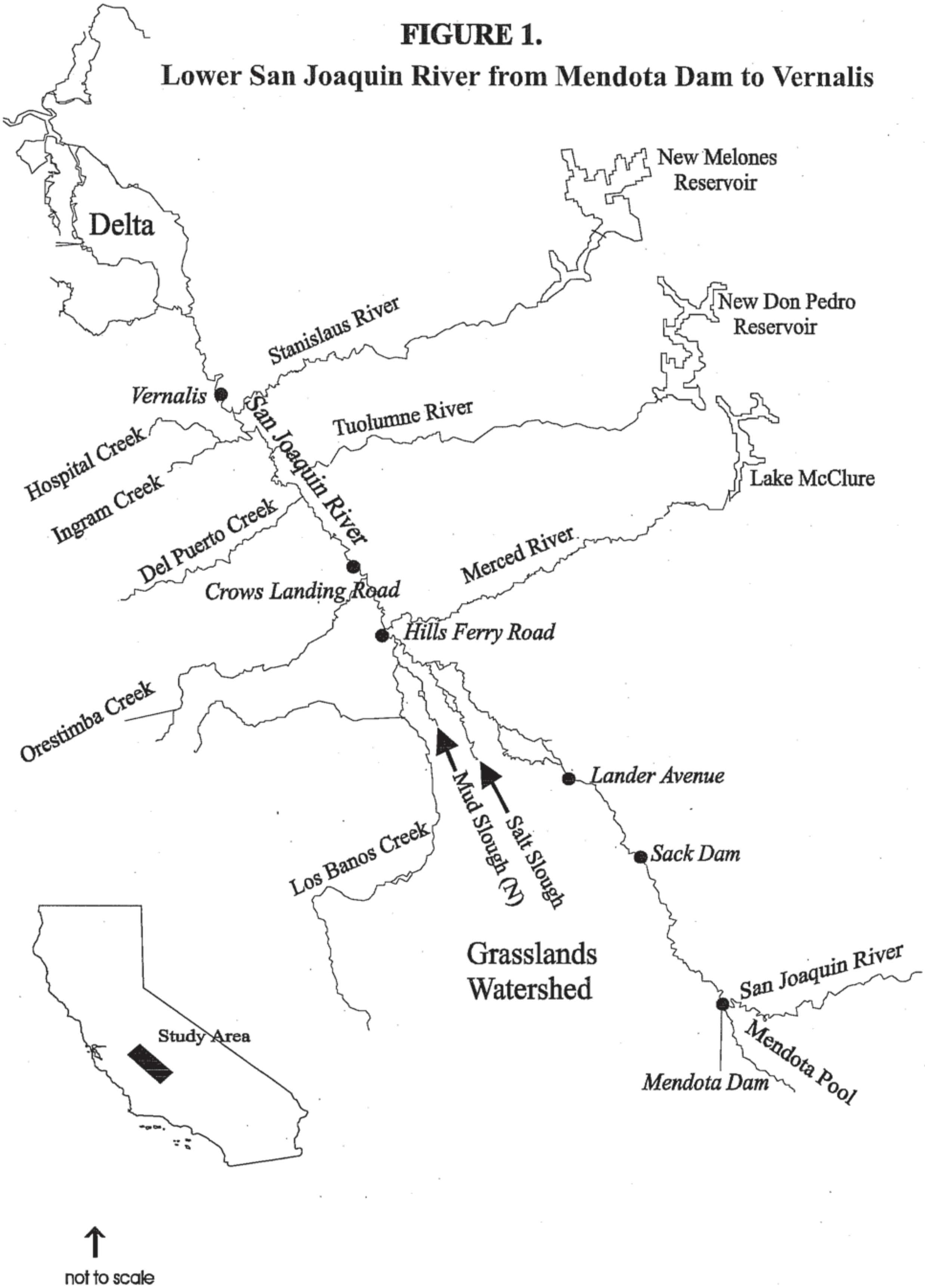
BORON IN THE ENVIRONMENT

Boron is a rare element widely distributed and bound to oxygen in nature. According to the European Centre for Ecotoxicology and Toxicology of Chemicals, 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). Absent in the elemental form in nature, boron normally occurs in mineral deposits as sodium borate (borax) or calcium borate (colemanite), and is found mostly in sedimentary deposits and sediments but also in metamorphic and igneous rocks. Its occurrence in sedimentary material is highly variable, with generally higher concentrations in marine deposits than in lacustrine and fluvial sediments (Perry and Suffet, 1994). Boron in sea water has concentrations typically of 5 mg/L (ECETOC, 1997).

According to Butterwick, *et al.*, (1989) and as summarized by Perry and Suffet (1994), boron has been found in surface waters across the United States with the highest concentrations occurring in the Lake Erie, Colorado basin, and Western Gulf regions. In the Lake Erie Basin, boron ranged from 0.028 to 0.700 mg/L with a mean of 0.210 mg/L. In the Colorado River Basin, boron ranged from 0.011 to 1.80 mg/L with a mean of 0.179 mg/L; 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 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 because of 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, has concentrations between 4 and 26 mg/L. Geothermal activity in central Italy has 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 were as high as 6.9 mg/L. An extraordinarily high level of boron, 72 to 80 mg/L was found in public water supplies in France at Cambronne - les - Clermont. These elevated concentrations were the result of an old industrial waste disposal site. Sewage water in Egypt contained 1.67 mg/L boron. Boron as high as 2.5 mg/L has been detected in Germany. Crude sewage in the UK averaged 3.3 to 3.6 mg/L boron.

FIGURE 1.
Lower San Joaquin River from Mendota Dam to Vernalis



ENVIRONMENTAL CHEMISTRY OF BORON

Boron chemistry in fresh water approximates that observed in pure water. In most cases boron is trivalent (Nemodruk and Karalova, 1969). Its fundamental chemistry involves two chemicals, boric acid $B(OH)_3$ and borate or boric oxide (B_2O_3). The equilibrium chemistry between the two compounds is:

$$B_2O_3 \leftrightarrows HBO_2 \leftrightarrows B(OH)_3$$

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). Chemical speciation varies with acidity according to the following equilibrium equation:

$$B(OH)_3 + H_2O \leftrightarrows B(OH)_4^- + H^+$$

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 boric acid $B(OH)_3$ will be approximately 20 times greater than borate ion $B(OH)_4^-$. Boron chemistry in fresh water involves these two chemicals, $B(OH)_3$ and $B(OH)_4^-$. Boric acid accounts for approximately 95% of the total dissolved boron in freshwater systems; the borate ion is approximately 5% (Perry and Suffet, 1994). Both compounds adsorb on clays and oxide surfaces (Keren and Bingham, 1985).

Boron exists in several forms in the soil as nonionic or anionic forms (Eisler, 1990). According to Keren and Bingham (1985), the predominant forms of boron in soil solutions with pH greater than 7 are $B(OH)_3$ and $B(OH)_4^-$. $B(OH)_3$ dominates at pH less than 7. Soils on the average have higher boron content than rocks (Klasing & Pilch, 1988).

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 confuse the relationship between laboratory and field results. For example, increasing levels of soil salinity likely enhances boron tolerance of many plant species (Ferreyra, *et al.*, 1997).

BORON IN THE CENTRAL VALLEY REGION

The Regional Board staff has evaluated levels of boron in the Central Valley of California. In the 1987 and 1988 staff surveyed selected California streams to determine natural background concentrations of trace elements believed to be free of agricultural drainage and urban and industrial discharges (Westcot, *et al.*, 1990). The survey showed that boron occurs in streams throughout 177 California streams having a median total boron concentration of 0.08 mg/L. It was generally the most abundant trace element in unpolluted water. Eighty percent of the streams sampled showed boron concentrations less than 1 mg/L. The highest total boron concentration in the survey was 12.5 mg/L and was found in Panoche Creek west of Interstate 5 in Fresno County. Panoche Creek is in the Lower 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). Many of the creeks surveyed drain into the Lower San Joaquin River watershed. Concentrations in 12 creeks draining into the Lower 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 Lower San Joaquin River watershed 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 were 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 waters 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. Compared to the west side drainages, the tributaries draining the Sierra Nevada have minimal boron.

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

Figure 2 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 from 0.01 to 1.2 mg/L for Airport Way.

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

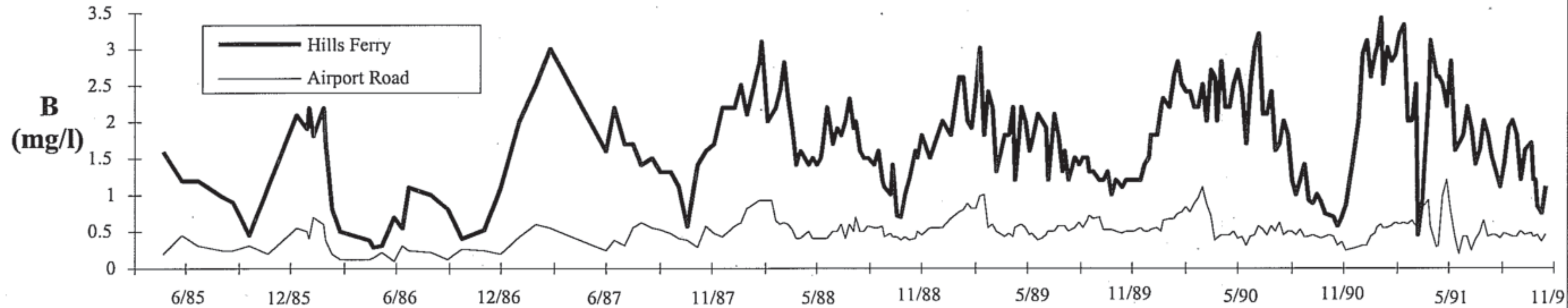
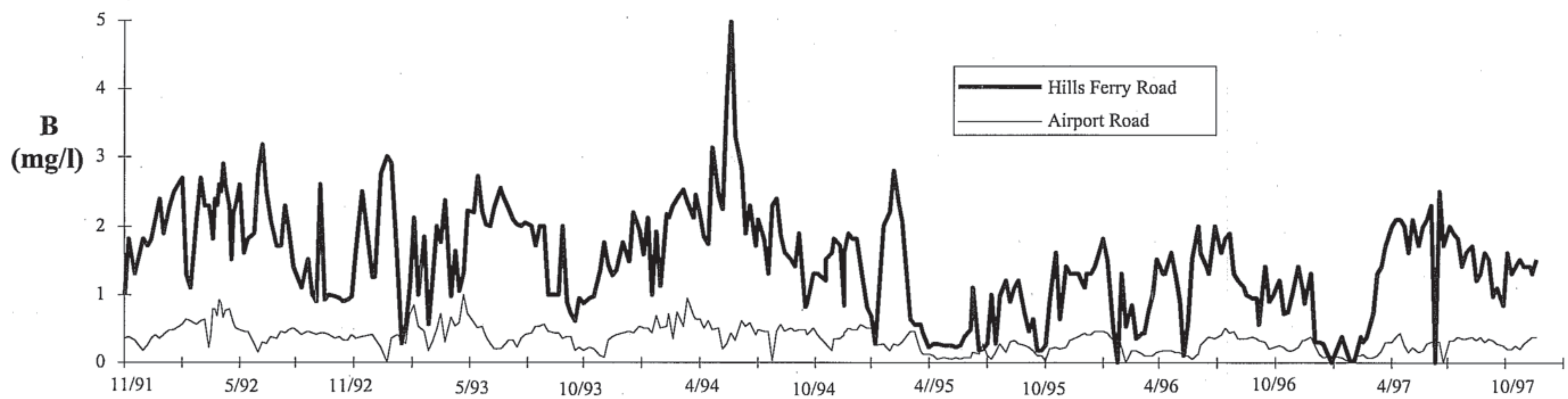


Figure 2. Comparison of Boron Concentrations for the San Joaquin River at Hills Ferry Road and Airport Way (continued) ; 1 November 1991 through 15



EFFECTS OF BORON ON BENEFICIAL USES

A number of reports summarize the toxicity of boron. In 1972, R. W. Sprague, while working as a chemist for the U.S. Borax Research Corporation published *The Ecological Significance of Boron,* which 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 mostly the United States and European literature. The U.S. Department of the Interior published guidelines for interpretation of selected irrigation water quality constituents including boron (USDI, 1998).

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

Crop

In relatively small quantities, boron is essential for the growth of higher plants; in slightly greater amounts it is toxic. Boron toxicity in plants is characterized by leaf malformation (such as, leaf cupping in young grape leaves), and by chlorotic and necrotic patterns within leaves, although some sensitive fruit crops (such as stone and pome fruits) develop twig dieback and gummosis rather than exhibiting leaf injury when exposed to toxic levels (Maas, 1990). Some crops may exhibit leaf injury with reduced yields at low concentrations (Maas and Gratten, 1999).

In Table 1, crops are grouped according to their 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 eight 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 adsorption, but toxicity may occur if that capacity is exceeded causing an increase boron availability and uptake in plants (Eisler, 1990; Gupta, *et al*., 1985). The amount of hydroxy-aluminum, iron, and magnesium has a major role in boron adsorption in soils.

Butterwick, *et al.,* (1989) summarized other factors that affect boron toxicity to higher terrestrial plants. Boron uptake by plants is reduced with increasingly alkaline (higher pH) conditions. Increased nitrogen in some cases has also decreased the severity of boron toxicity. Experiments on the leaching of soil boron showed that a large percentage of it can be removed by percolating waters, but remaining boron can be persistent. Fields contaminated with it can be difficult to reclaim under field conditions (Prichard, 1999).

Cattle

Butterwick, *et al.*, (1989) summarized two drinking water studies on boric acid toxicity to cattle. In the first study, swelling and irritation of legs, lethargy, and diarrhea occurred from 30 days exposure to boric 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). 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.

Other publications indicate criteria levels. Ayers and Westcot (1985) provided a guideline of 5 mg/L for livestock drinking water. 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 to 150 mg/L as "safe", and over 150 mg/L as having adverse effects.

Drinking Water

Because of the lack of information regarding concentrations, forms, and relative toxicity of dietary boron compounds, Klasing and Pilch (1988) stated that it was impossible 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. Additional studies were particularly needed to determine chronic dose-response effects.

Murry (1995) did a human health risk assessment for the Soap and Detergent Association 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 childbearing age. An average diet of 1.5 mg boron/day 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. Murry also cites Nielsen (1994) as suggesting that boron is a probable essential trace element for humans.

Table 1. Relative Boron Tolerance Of Agricultural Crops
(Maas, 1990; Maas and Gratten, 1999)

Very Sensitive (<0.5 mg/L)*

Blackberry	*Rubus spp.*
Lemon	*Citrus limon*

Sensitive (0.5-0.75 mg/L)

Apricot	*Prunus armeniaca*
Avocado	*Persea americana*
Cherry	*Prunus avium*
Fig, kadota	*Ficus carica*
Grape	*Vitis vinifera*
Grapefruit	*Citrus X paradisi*
Orange	*Citrus sinensis*
Peach	*Prunus persica*
Pecan	*Carya illinoiensis*
Persimmon	*Diospyros khaki*
Plum	*Prunus domestica*
Walnut	*Juglans regia*

Sensitive (0.75-1.0 mg/L)

Artichoke, Jerusalem	*Helianthus tuberosus*
Bean, kidney	*Phaseolus vulgaris*
Bean, Lima	*Phaseolus lunatus*
Bean, mung	*Vigna radiata*
Bean, snap	P. vulgaris
Lupine	*Lupinus hartwegii*
Peanut	*Arachis hypogaea*
Sesame	*Sesamum indicum*
Strawberry	*Fragaria sp*
Sunflower	*Helianthus annuus*
Sweet potato	*Ipomoea batatas*
Wheat	*Triticum aestivum*

Moderately Sensitive (1.0 - 2.0 mg/L)

Broccoli	*Brassica oleracea*
Carrot	*Daucus carota*
Cucumber	*Cucumis sativus*
Lettuce	*Lactuca sativa*
Pea	*Pisum sativa*
Pepper, red	*Capsicum annuum*
Potato	*Solanum tuberosum*
Radish	*Raphanus sativus*

Moderately Tolerant (2.0-4.0 mg/L)

Artichoke	*Cynara scolymus*
Bluegrass, Kentucky	*Poa pratensis*
Cabbage	*Brassica oleracea, capitata*
Cauliflower	*B. Oleracea botrytis*
Clover, sweet	*Melilotus indica*
Cowpea	Vigna unguiculata (L.) Walp
Maize/corn	*Zea mays*
Muskmelon	*Cucumis melo*
Mustard	*Brassica juncea*
Oat	*Avena sativa*
Squash, scallop	*Cucurbita pepo*
Turnip	*Brassica rapa*

Tolerant (4.0-6.0 mg/L)

Alfalfa	*Medicago sativa*
Beet, red	*Beta vulgaris*
Garlic	*Allium sativum*
Parsley	*Petroselinum crispum*
Sugar beet	*Beta vulgaris*
Tomato	*Lycopersicon*
Vetch, purple	*Vicia benghalensis*

Very Tolerant (6.0-15.0 mg/L)

Asparagus	*Asparagus officinalis*
Celery	*Apium graveolens*
Cotton	*Gossypium hirsutum*
Onion	*Allium cepa*
Sorghum	*Sorghum bicolor*

NOTE: * Classification for tree and vine crops is 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 also indicates the classifications of citrus, avocados, and grapes may be less sensitive than indicated.

Human health levels and recommendations by U.S. EPA were based on a 2-year study toxicity study performed on dogs and rats by Weir and Fisher (1972). 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 the 2-year dog study (Morry, 1998). Based on the dog study the US EPA NOAEL is lower than the NOAEL that Murry (1995) used based on the rat study. US EPA IRIS database calculations indicate that the dog is more sensitive than the rat to boron compounds. Based on the dog study, 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, which continually involves examining substances simultaneously for all routes of exposure and health effects, cancerous or non-cancerous. The IRIS process is an on-going process. The suggested no–adverse–response level (SNARL) is 0.63 mg/L rounded down to 0.60 mg/L. The state action level of 1.0 mg/L was based on the 1972 rat toxicity results.

Aquatic Bird

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 in mg/kg. Conversion from boron toxicity results in kg/kg in food to mg/L in water is uncommon. Smith and Anders (1989) reported exposure to 1,000 mg/kg dietary boron in breeding mallards caused an increase in embryo and hatchling mortality. Embryo growth reduction was observed 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 greater, respectively, 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/mg. 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 like 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.

Results are from evaporation pond studies, which may behave differently than at a free flowing river system such as the San Joaquin River, can give an estimate of the relative water related boron toxicity to aquatic birds. Skorupa (1998) stated that there is an extensive database from that was compiled as part of the San Joaquin Valley Drainage Program, and that Moore, *et al.*, (1989) found:

> *At Barbizon Farms evaporation pond (Tulare Lake Bed area) in spring of 1987, impounded water contained 8-12 mg/l boron with associated avian food chain values of 30-90 mg/kg boron in aquatic invertebrates, and 300-350 mg/kg boron in aquatic plants.*

Skorupa (1998) concluded from Moore's data that some species of aquatic birds, such as American Coots and Redhead Ducks, feed largely on aquatic plants (even during the breeding season), and that 8 to 12 mg/l boron at the Barbizon Farms ponds was sufficient to produce aquatic plants with 300-350 mg/kg tissue boron or 10-times more than the 30 mg/kg lowest toxic dietary threshold from captive feeding studies. The waterborne threshold for producing aquatic plants with at least 30 mg/kg tissue boron is likely to be substantively below 8 to 12 mg/l waterborne boron. Skorupa (1998) concluded that a review of the evaporation pond data from one site alone indicates that the waterborne boron toxicity threshold for aquatic birds is probably lower than 8 mg/l.

Fish and Amphibian

Fish and amphibian sensitivity to boron varies widely by species. 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 (LC_{50}) for a 15 month-old rainbow trout was 339 mg/L boron in water. EPA (1972) states that the Wurtz (1945) study found that 5,000 mg/L caused discoloration of the skin on trout.

EPA (1972) summarized Wallen, *et al.*, (1957) as having established a 96-hour lethal concentration where 50% mortality occurs (LC_{50}) 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 (mortality and teratogenesis) in the early life (embryo alevin, posthatched, larval, or early fry) 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 (LC_1) and 50% mortality (LC_{50}) occurred in mg/L boron as follows:

Aquatic Species	Stage	Exposure	LC_1	LC_{50}
trout, rainbow	embryo, alevin	28 days	0.001 to 0.1	27 to 100 mg/L
goldfish	embryo, fry	7 days	0.2 to 1.4	46 to 75 mg/L
catfish, channel	embryo, fry	9 days	0.2 to 5.5	22 to 155 mg/L
amphibians	embryo, larva	7.5 days	3 to 25	47 to 145 mg/L

LC_{50} values were significantly higher than LC_1 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. From an analysis of variance, they also concluded 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, boron concentrations of 100 to 300 mg/L were lethal for all species tested. LC_1 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. A comprehensive No Observed Effect Level (NOEC) would be 0.75 mg/L boron for rainbow trout embryo-laval stages.

A European report on boron states that rainbow trout (*Oncorhynchus mykiss)* and zebra fish (*Brachydanio rerio*) are the most sensitive fish species (ECETOC, 1997). Zebra fish are not found in the Lower San Joaquin River. Rainbow trout embryo-larval stages are particularly sensitive having a boron no-effect threshold of approximately 1 mg/L. ECETOC suggested a NOEC of approximately 1 mg/L based on Black, *et al*, 1993 results showing LOEC values of 1.10, 1.24, and 1.73 mg/L boron at three different locations in the United States. They also cited a survey of 37 fisheries biologists concerning boron concentrations of selected Western United States 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 1 mg/L had viable trout populations (EA Engineering, 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 (1972) 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:

Exposure Duration	Boron Concentration (mg/L)
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 LC_{50} of 113 mg/L of boron. Chinook salmon (*Oncorhynchus* *tshawytscha*) as "swim-ups" and advanced fry had a 4-day LC_{50} of 725 mg/L as reported by Hamilton and Buhl (1990), who also reported Coho salmon as "swim-ups" and advanced fry had a 4-day LC_{50} of 447 mg/L boron. Hamilton and Wiedmeyer (1990) found no boron detected in chinook salmon 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 elevated 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 Lower San Joaquin River that receives 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 that simulated water quality of 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 three fish species. Acute toxicity for boron at the 96-hour LC_{50} ranged from greater than 100 to 527 mg/L.

Other Aquatic Life

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 Eurasia Watermill (*Myriophyllum spicatum)* after 32 days of treatment. Glandon and McNabb (1978) observed no adverse effects on duckweed (*Lema minor*) growth at exposures of 0.01, 0.11 and 1.01 mg/L boron. ECETOC (1997) cited a German study in 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.

Perry and Suffer (1994) reviewed research on the toxicity of boron and duckweed. 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. In an abstract from a German publication, reduction in photosynthesis was observed in duckweed at 1 mg/L, based on an exposure of 28 days (Noble, 1981). No details of the article were available in English to evaluate the methodology for developing objectives. Wang (1986) noted a 96 hours LC_{50} of 60 mg/L boron for duckweed.

Perry and Suffet (1994) also reviewed boron toxicity for a number of algae species 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. prothicoides 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.

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. According to Anita and Cheng (19750 and Eisler (1990), phytoplankton can tolerate up to 10 mg/L inorganic boron in the absence of other stresses.

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, *Anthocidaris crassispina*). In an abstract of a German article cited by Perry and Suffer (1994), Bringmann (1978) noted that cell replication in the fresh water protozoan (*Entosiphon sulcatum*) was reduced by only 5 percent when exposed to 1 mg/L boron for 3 days. No details of the article were available in English to evaluate the methodology for developing objectives. Kapu and Schaeffer (1991) examined behavior responses in the flatworm planarian (*Dugesia dorotocephala*) 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. However, the experiment had design flaws including lack of control populations; therefore, cannot be used in setting objectives. Data from European invertebrate tests showed that chronic toxicity for borate is above 6 mg/L (ECETOC, 1997).

A few studies focused on determinating acute and chronic lethal and sublethal effects of boron on the water flea (*Daphnia magna*). NOEC and 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 LC_{50} values of 226 and 133 mg/L, and 21-day LC_{50} values of 53.2 and 52.2 mg/L.

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 LC_{50} for the water flea (*Daphnia magna*) was 141 mg/L. The 48-hour LC_{50} 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.

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).

After summarizing toxicity data for amphibians, invertebrates, algae and other aquatic life, Butterwick, *et al.* (1989), 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. Preliminary investigations by US EPA (1975) showed a 48-hour LC_{50} boron concentration of 700, 1,748, and 2,797 mg/L for four stages of development for the most sensitive species of mosquito larvae.

WATER QUALITY CRITERIA FOR BORON

This report section summarizes the criteria, goals, and reference numbers as found in the literature relative to setting objectives in the Lower San Joaquin River. Neither the US EPA National Ambient Water Quality Criteria, California Ocean Plan, nor US EPA National Ambient Water Quality Criteria have set boron standards.

No California or Federal drinking water standards have been established for boron. However, based on a two 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 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 is a Suggested No-Adverse-Response Level (SNARL) for toxicity other than cancer. The Chilean boron standard was set at 4 mg/L boron in water used for human consumption and reflected high natural concentrations in fresh water of northern Chile (ECETOC, 1997).

The California Department of Health Services published a state action level of 1.0 mg/L (Marshack, 1998). California State and other health advisory drinking water levels are for use of water in drinking water supplies. Application depends on treatment costs and community response. Action levels act as surrogates for Maximum Contaminant Levels (MCLs); however, they are not technically enforceable by the Department of Health Services on water suppliers as are MCLs.

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, 1998). Ayers and Westcot (1985) recommended a concentration of 0.7 mg/L boron in water that would require no restriction for agricultural use.

The State Water Resources Control Board Technical Committee 1987 final report (SWRCB, 1987, Table IV-7) recommended a continuous criterion for agricultural of 0.5 mg/L. They concluded that aquatic toxicity data for boron were sparse. Using LC_{50} 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*)*. The Technical Committee in 1987 estimated lowest effect level was also based on a national average boron concentration of 0.1 mg/L. They recommended an instantaneous maximum criterion of 5.8 mg/L for boron, and a continuous water quality criterion of 0.760 mg/L.

Table 2. Adverse Effects From Boron On Freshwater Aquatic Organisms

(updated from SWRCB, 1988)

Species	Boron (mg/L)	Effect	Duration	Reference
Rainbow trout embryo/larvae	1.02	LC_{10}	28 Days	Birge, *et al.*, 1980
Water Plant *Elodea canadensis*	2.0	Photosyn.	28 Days	Nobel, 1981
Water flea *Daphnia magna* (<24 hour)	13.0	Reprod.	21 Days	Lewis & Valentine, 1981
Daphnia magna (<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
Myriophyllum spicatum	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 *Anabaena* PCC 7119	50	Growth	96 Hours	Martinez, *et al,* 1986
Daphnia magna	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 *Neomysis mercedis*	64.7	LC_{50}	14 Days	Bailey & Joe, 1986
Goldfish	65.0	LC	7 Days	Birge & Black, 1977
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 *Anacystis nidulans*	75	Growth	96 Hours	Martinez, *et al.*, 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, *et al.,* 1976
Daphnia magna	133	LC_{50}	2 Days	Lewis & Valentine, 1981
Daphnia magna	141	LC_{50}	2 Days	Maier & Knight, 1991
Duckweed L*ema minor*	200	Growth	3 Days	Frick, 1985
Daphnia magna	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

The Technical Committee Report (SWRCB, 1988) concluded that aquatic toxicity data for boron was limited and did not allow a very high degree of confidence. However, they calculated a criterion of 0.55 mg/L based on a modified Ocean Plan method with a log mean of 2.98 mg/L of the concentrations of the three most sensitive species:

1.02 mg/L LC_{10} for rainbow trout (embryo/larva)

2.0 mg/L for *Elodea canadensis*

13.0 mg/L for *Daphnia magna*

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

ln 1.02 = 0.019

ln 2.0 = 0.693

ln 13.0 = 2.564

mean of the
natural log = 1.092

Taking the anti-logarithm:

e^x of 1.092 = 2.98 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 = -2.3

mean of the
natural log = -0.605,

and taking the antilogarithm to determine the concentration:

e^x of -0.605 = 0.55 mg/L.

Using the Ocean Plan method, which has a built-in safety factor, a boron concentration of 0.55 mg/L was recommended as an interim criterion. The Technical Committees number was based on an unusually low LC_{10} of 1.02 mg/L for rainbow trout in Birge and Black (1981) and a national boron mean concentration 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 criterion of 0.77 and 0.94 mg/L, respectively. Existing boron concentrations at Airport Way and Hills Ferry Road (Figure 2) are considerably high than 0.3 mg/L. Boron concentrations from Fremont Ford to Maze Road ranged from 0.21 to 0.32 mg/L from 1951 to 1954 (DWR, 1956).

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 also using the more protective Ocean Plan method, the UC Consultants 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 were considered likely more sensitive to boron than animals.

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 would also protect wildlife. Robert April based this advice on their rough assessment of laboratory values and the low potential for boron to bioaccumulate in wildlife. However, these numbers were preliminary with no completed technical support (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. ECETOX recommended a NOEC of 1.0 mg/L boron based rainbow trout toxicity, and Black, *et al.,* 1993 stated that rainbow trout embryo and larva stages should be protected boron concentrations under 0.75 to 1.0 mg/. As summarized by Eisler (1990), Papachristou *et al.* (1987) recommended a generalized boron criteria of 5 mg/L for fish. Further, the U.S.D.I. guidelines for boron predicted a no adverse affect levels for fish and aquatic invertebrates at 5 and 6 mg/L, respectively.

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, the effects of boron on aquatic biology vary widely. Amphibians appear 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 on aquatic organisms shows that the embryo/larval stages of the rainbow trout are the most sensitive to borate. Birge and Black (1977) state that high concentrations of boron (25-200 mg/L) are 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 a reasonable and environmentally acceptable limit for rainbow trout. Skorupa (1998) indicated that water concentrations in evaporation ponds of less than 8 to 12 mg/L may result in concentrations high enough within aquatic invertebrates and plants 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 for humans have been established for boron. However, as a reference, the California Department of Health Services 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.

Table 3. Summary Of Boron Effect Levels In Water

	BORON (mg/L)	REFERENCE
Crops		
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
Fish and Amphibians		
Rainbow Trout (embryo/alevin) NOEC	0.75-1.0	Black, *et al.*, 1993; ECETOC, 1997
Chinook Salmon, (swim up, advanced stages) 96-hr. LC_{50}	>100	Hamilton & Buhl, 1990
Amphibians, (embryo, larva) 7.5 dayLC_{50}	47-145	Birge & Black, 1977
Channel Catfish, (embryo, fry) 9-day LC_{50}	22-155	Birge & Black, 1977
Aquatic Birds		
Ducks Feeding on Evaporation Pond Plants	<8-12	Skorupa, 1998
Freshwater Plants		
Eurasia Watermill, 32 days 50% Inhibited in Root Growth	30	Stanley, 1974
Duckweed signs of Toxicity after 3 Days Decrease in Growth after 6 days	200	Frick, 1985
Duckweed Normal Growth	10-20	Frick, 1988
Aquatic Plants in General	4	Papachristou, *et al.*, 1987
Algae		
Green Algae (*Chlorella vulagaris*) Reduction in Growth	50	Bowen and Gauch, 1966
C. prothicoides and C. emersanii Reduction in Growth	100	Bowen and Gauch, 1966
Blue Green (*Anacystis nidulans*) Decrease in Growth Rate Chlorophyll Content from 96-hr. exposure	75 and 100	Martinez, *et al.*, 1986

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

	BORON (mg/L)	REFERENCE
Bacteria, Protozoa and Invertebrates		
Water Flea (*Daphnia magna*)		
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
Daphnia magna two day LC_{50}	141	Maier and Knight, 1991
Midge (*Chironomus decorus*) two day LC_{50}	1,376	Maier and Knight, 1991
Mosquito Larvae two day LC_{50}	700-2,797	US EPA, 1975
Livestock Drinking Water		
United Nations Guidelines	5	Ayers & Westcot, 1985
Eisler (1990; table 10) was referenced as a source document for:		
Maximum Allowable In National Academy of Science Publication	5	NAS, 1980; Weeth, *et al.*, 1981 Green & Weeth, 1977
Maximum Tolerated	40	Seal & Weeth, 1980
"Safe"	40-150	Green & Weeth, 1977
Adverse Effects	>150	Nielsen, 1986
Human Drinking Water		
State Action level	1.0	California DHS (Marshack, 1998)
Iris, Reference Dose as a Drinking Water Level	0.63	US EPA IRIS Database (Marshack, 1998)
US EPA SNARL	0.60	Marshack, 1998
Risk Assessment	4	Murry, 1995

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. However, USDI (1998) guidelines state that boron can be bioconcentrate to varying degrees by lower level aquatic organisms, specifically algae and aquatic insects. 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. Saiki believes that more studies are needed before objectives can be set that can confidently protect fish and wildlife resources.

Saiki (1998) also has expressed some concerns over the concentration of boron in algae and the possibility of their consumption by fish or wildlife as follows:

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 criteria and 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. In their review of the literature, Perry & Suffet (1994) 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 a better data base needs to be developed before final objectives for boron within the San Joaquin River system can be set.

Glossary

LC_1	The lethal concentration (LC) at which 1% of the test population dies.
LC_{10}	The lethal concentration at which 10% of the test population dies.
LC_{50}	The lethal concentration at which 50% of the test population dies.
LD_{50}	The lethal dose (LD) of a toxicant to 50% of the test population.
LOAEL	Lowest observed adverse effect level is the lowest dose resulting in an adverse effect.
LOEC	Lowest observed effect level is the lowest concentration that causes a statistically significant effect different from the controls.
MCL	Maximum contaminant level
MLD	Minimum lethal dose is concentration required to kill one or more of the test species.
NOEC	No observed effect level is the lowest concentration that causes a statistically significant effect different from the controls.
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 from the controls.

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