

Regulatory Determinations Support Document
for Selected Contaminants from the Second
Drinking Water Contaminant Candidate List
(CCL 2)

Part II:
CCL 2 Contaminants Undergoing Regulatory
Determination

Chapter 3: Boron

A chapter from:

**Regulatory Determinations Support Document for Selected Contaminants
from the Second Drinking Water Contaminant Candidate List (CCL 2)**

EPA Report 815-R-08-012

Executive Summary

Boron, an inorganic compound (IOC), is a non-volatile metalloid that is ubiquitous in the environment in compounds called borates. Common borates include boron oxide, boric acid, and borax. Anthropogenic boron compounds include boron halides (e.g., boron trichloride and boron trifluoride). Borates and other boron compounds are used in the production of glass, ceramics, soaps, fire retardants, pesticides, cosmetics, photographic materials, and high energy fuels.

Boron enters the environment mainly through the weathering of rocks, boric acid volatilization from seawater, and volcanic and geothermal activity. To a lesser extent, boron is released to the environment from anthropogenic sources (e.g., via industrial air emissions, fertilizer and herbicide applications, and industrial and municipal wastes). Limited data are available on the quantity of anthropogenic releases. Toxic Release Inventory (TRI) data suggest that air emissions dominate industrial boron trihalide releases. Boron trichloride releases fluctuate in the range of hundreds of pounds per year, and boron trifluoride releases fluctuate in the range of tens of thousands of pounds per year. Around 1990, the quantity of boron minerals used annually for agricultural purposes was estimated to have been approximately 293,000 pounds.

The Institute of Medicine of the National Academies categorizes boron as a possible trace mineral nutrient for humans. It may interact with Vitamin D and calcium homeostasis, influence estrogen metabolism, and play a role in cognitive function. The estimated average dietary intake of boron in U.S. male adults is 1.5 mg/day. Large doses (on the order of 20 mg/kg or more) can cause nausea and vomiting. Chronic low-level oral exposure causes developmental defects in animal subjects. Based on developmental defects in rats, the EPA reference dose (RfD) for boron is 0.2 mg/kg/day. EPA calculated a health reference level (HRL) of 1.4 mg/L or 1,400 µg/L for boron using the RfD of 0.2 mg/kg-day and a 20 percent screening relative source contribution (RSC). Sensitive subpopulations may include developing fetuses and individuals with impaired kidney function.

EPA evaluated boron occurrence in drinking water using data collected from 989 ground water public water systems (PWSs) by the National Inorganics and Radionuclides Survey (NIRS). The NIRS data indicate that approximately 4.3 percent of the ground water PWSs had detections of boron at levels greater than 700 µg/L (1/2 the HRL), affecting approximately 2.9 percent of the population served by these ground water systems. Approximately 1.7 percent of the ground water PWSs had detections of boron at levels greater than 1,400 µg/L (the HRL), affecting approximately 0.4 percent of the population served by these ground water systems.

Because NIRS only investigated ground water systems, the Agency evaluated the results of a survey funded by the American Water Works Association Research Foundation (AwwaRF) to gain a better understanding of the potential occurrence of boron in surface water systems. Of 341 samples analyzed for boron, approximately 67 percent represented ground water sources and 33 percent represented surface water sources. Of the ground water sources, 3.1% had boron concentrations that exceeded the HRL of 1,400 µg/L; the highest observed concentration was approximately 3,300 µg/L. In contrast, none of the surface water sources exceeded the boron HRL of 1,400 µg/L, and the highest concentration in surface water was 345 µg/L. These results

indicate that boron contamination occurs less frequently and at lower concentrations in surface water than in ground water.

EPA evaluated supplementary data on boron occurrence in ambient and drinking water from additional sources, including the United States Geological Survey (USGS) National Ambient Water Quality Assessment (NAWQA) program and the Community Water System Survey (CWSS).

The Agency has made a determination not to regulate boron with a national primary drinking water regulation (NPDWR). While boron was found at levels greater than the HRL (and ½ the HRL) in several of the ground water systems surveyed by NIRS, it was not found at levels greater than the HRL (or ½ the HRL) in the surface waters sources evaluated in the AwwaRF study. Taking this surface water information into account, the Agency believes the overall occurrence and exposure from both surface and ground water systems together is likely to be lower than the values observed for the NIRS ground water data. Because boron is not likely to occur at levels of concern when considering both surface and ground water systems, the Agency believes that an NPDWR does not present a meaningful opportunity for health risk reduction.

The Agency plans to update the Health Advisory for boron to provide more recent health information. The updated Health Advisory will provide information to any States with public water systems that may have boron above the HRL. If a State finds highly localized occurrence of boron at concentrations above the HRL, it should consider whether State-level guidance (or some other type of action) may be appropriate.

The Agency's regulatory determination for this contaminant is presented formally in the *Federal Register*.

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Abbreviations

AwwaRF	American Water Works Association Research Foundation
BMD	Benchmark Dose
CAS	Chemical Abstracts Service
CCL 2	Second Contaminant Candidate List
CWSS	Community Water Systems Survey
GW	Ground Water
HF	Hollow-Fiber
HRL	Health Reference Level
ICP	Inductively Coupled Plasma
ICP-AES	Inductively Coupled Plasma-Atomic Emission Spectrometry
IOC	Inorganic Compound
IOM	Institute of Medicine
LOAEL	Lowest-Observed-Adverse-Effect Level
MDL	Method Detection Limit
MRL	Minimum Reporting Level
MTBE	Methyl Tertiary Butyl ether
NAWQA	National Water Quality Assessment
NIRS	National Inorganics and Radionuclides Survey
NOAEL	No-Observed-Adverse-Effect Level
NPDWR	National Primary Drinking Water Regulation
PTFE	Polytetrafluoroethylene
PWS	Public Water System
RfD	Reference Dose
RO	Reverse Osmosis
RSC	Relative Source Contribution
SM	Standard Method
SW	Spiral-Wound
SW	Surface Water
TRI	Toxics Release Inventory
USGS	United States Geological Survey

3 Boron

3.1 Definition

Boron, an inorganic compound (IOC), is a non-volatile metalloid that is ubiquitous in the environment in compounds called borates. Common borates include boron oxide, boric acid, and borax. Anthropogenic boron compounds include boron trichloride and boron trifluoride. The Chemical Abstracts Service (CAS) registry number of elemental boron is 7440-42-8. Borates and other boron compounds have their own registry numbers.

3.1.1 Properties and Sources

Elemental boron is not readily found in nature, yet borates are natural and ubiquitous. Elemental boron exists as a solid at room temperature, either as black monoclinic crystals or as a yellow or brown amorphous powder when impure. Boron is an essential nutrient for plants and an essential element for many organisms (USEPA, 1994a). Borates are most predominantly found in nature in oceans, sedimentary rocks, coal, shale, and some soils. Boron enters the environment mainly through the weathering of rocks, boric acid volatilization from seawater, and volcanic and geothermal activity (HSDB, 2004; ATSDR, 1992). To a lesser extent, boron is also released to the environment through anthropogenic sources. Anthropogenic boron compounds include boron halides (boron trichloride and boron trifluoride) as well as borates. Boron compounds are used in the production of glass, ceramics, soaps, fire retardants, pesticides, cosmetics, photographic materials, and high energy fuels (USGS, 2004; ATSDR, 1992). Boron compounds are registered as pesticides in the U.S. for use as insecticides, herbicides, and fungicides. In such roles, boron compounds can act in a number of ways, such as through poisoning, desiccation, or inhibition of growth (USEPA, 1994a). The production and use of products containing boron compounds adds to the release of boron into the environment. Physical and chemical properties of boron and selected boron compounds are summarized in Exhibit 3-1.

Exhibit 3-1: Physical and Chemical Properties

Identification: Boron and Boron Compounds							
	<i>boron</i>	<i>boron oxide</i>	<i>boric acid</i>	<i>borax</i>	<i>borax, anhydrous</i>	<i>boron trichloride</i>	<i>boron trifluoride</i>
CAS number	7440-42-8	1303-86-2	10043-35-3	1303-96-4	1303-96-4	10294-34-5	7637-07-02
Molecular Formula	B	B ₂ O ₃	H ₃ BO ₃	Na ₂ B ₄ O ₇ • 10H ₂ O	Na ₂ B ₄ O ₇	BCl ₃	BF ₃
Physical and Chemical Properties							
Boiling Point	2,550 °C ¹	1,500 °C ¹	-1 ^{1/2} H ₂ O, 300 °C ¹	-10H ₂ O, 320 °C ²	Decomposes at 1,575 °C ¹	12.5 °C ²	-99.9 °C ¹
Melting Point	2,300 °C ¹	450 ± 2 °C ¹	169 ± 1 °C tr to HBO ₂ ¹	75 °C, -8H ₂ O, 60 °C ²	741 °C ¹	-107 °C ²	-126.8 °C ¹
Molecular Weight	10.81 /mol ²	69.64 g/mol ²	61.84 g/mol ²	381.37 g/mol ¹	201.22 g/mol ¹	117.19 g/mol ²	67.81 g/mol ²
Log K _{oc}	-----	-----	-----	-----	-----	-----	-----
Log K _{ow}	-----	-----	-----	-----	-----	-----	-----
Water Solubility	insoluble ²	rapidly hydrates to boric acid ¹	63.5 g/L at 30 °C ¹	20.1 g/L at 0 °C ¹	10.6 g/L at 0 °C; 87.9 g/L at 40 °C ¹	decomposes ¹	1060 g/L at 20 °C ²
Vapor Pressure	1.56x 10 ⁻⁵ atm at 2,140 °C ²	-----	-----	-----	-----	100 mm Hg at 33.5 °C ¹	40 mm Hg at -131°C (solid); 760 mm Hg at -110.7 °C (liq) ¹
Henry's Law Constant	-----	-----	-----	-----	-----	-----	-----
Freundlich Isotherm Constant (K)	-----	-----	-----	-----	-----	-----	-----

¹ Weast, 1988 (as cited in ATSDR, 1992 and HSDB, 2004)

² Budavari, 1989 (as cited in HSDB, 2004)

3.1.2 Environmental Fate and Behavior

Little is known about the residence time of boron compounds in air, soil, or water. Limited data are available regarding their transport and partitioning in these media (ATSDR, 1992).

The adsorption of borates and boric acids to soils is controlled by the presence of aluminum and iron oxides and, to a lesser extent, organic matter (Bingham *et al.*, 1971; Sakata, 1987; Parks and White, 1952 all as cited in ATSDR, 1992). Soils rich in these oxides, like the Ultisols of the southeastern United States, will experience significant adsorption of available borates. In some environments, adsorption to soil particles may be irreversible (Rai *et al.*, 1986 as cited in ATSDR, 1992). Boron is found in soil (as borates) at an average concentration of 10 mg/kg (Weast, 1988 as cited in HSDB, 2004).

When released to the atmosphere, borates exist as particulate matter or aerosols, with a half-life on the order of days, depending on particle size and atmospheric conditions. Deposition can occur through dryfall, and wet deposition is also possible in the case of more soluble borates (USEPA, 1987 as cited in ATSDR, 1992).

In water, boron readily hydrolyzes and may polymerize in concentrated solutions (ATSDR, 1992). Adsorption to sediments is thought likely to be the most significant fate pathway for boron in water (Rai *et al.*, 1986 as cited in ATSDR, 1992). The extent of adsorption is determined by the pH of the water and the chemical composition of the sediment. The greatest adsorption takes place in a pH range of 7.5 to 9.0 (Keren *et al.*, 1981; Keren and Mezuman, 1981; Waggott, 1969 all as cited in ATSDR, 1992). Boron compounds in water may also co-precipitate as hydroxyborate compounds with aluminum, iron, or silicon (Biggar and Fireman, 1960 as cited in ATSDR, 1992). Boron is typically found in salt water at concentrations of 4.6 mg/L (Weast, 1988 in HSDB, 2004).

Aquatic plants and animals accumulate boron, but residues do not increase through the food chain (Moore, 1991). Even though it is found in many fruits and vegetables, boron does not accumulate in human tissues (Butterwick *et al.*, 1989 as cited in ATSDR, 1992; Waggot, 1969 as cited in ATSDR, 1992).

3.2 Health Effects

The Institute of Medicine (IOM, 2001) of the National Academies categorizes boron as a possible trace mineral nutrient for humans. Boron is essential for plant growth and deficiency studies in animals and humans have provided some evidence that low intakes of boron affects cellular function and the activity of other nutrients. It may interact with Vitamin D and calcium homeostasis, influence estrogen metabolism, and play a role in cognitive function (IOM, 2001). Iyengar *et al.* (1988, as cited in USEPA, 2004a) reported an average dietary intake of 1.5 mg/day for male adults based on the Food and Drug Administration Total Diet Study.

Some human oral data are available from cases where boron was ingested as a medical treatment. When the amount ingested was less than 3.68 mg/kg, subjects were asymptomatic, while doses of 20 and 25 mg/kg resulted in nausea and vomiting. Case reports and surveys of

accidental poisonings indicate that the lethal doses of boron range from 15 to 20 grams (approximately 200 to 300 mg/kg) for adults, 5 to 6 grams (approximately 70 to 85 mg/kg) for children, and 2 to 3 grams (approximately 30 to 45 mg/kg) for infants (USEPA, 2004b).

The primary adverse effects seen in animals after chronic exposure to low doses of boron generally involve the testes and developing fetus. Chronic effects of dietary boron exposure in two-year studies included testicular atrophy and spermatogenic arrest in dogs, decreased food consumption, suppressed growth, and testicular atrophy in rats, and decreased survival, testicular atrophy, and interstitial cell hyperplasia in mice. Although researchers observed some increases in tumor incidences in the liver and in subcutaneous tissues in mice, based on comparisons to historic controls, these tumors were determined not to be associated with exposure to boron from boric acid (USEPA, 2004b). Boron is not considered mutagenic and the Agency determined that there are inadequate data to assess the human carcinogenic potential for boron (USEPA, 2004a).

In developmental studies with rats, mice, and rabbits, oral exposure to boric acid resulted in decreased pregnancy rate, increased prenatal mortality, decreased fetal weights, and increased malformations in fetuses and pups. However, these reproductive effects were associated with maternal toxicity including changes in maternal organ weights, body weights, weight gain, and increased renal tubular dilation and/or regeneration (Price *et al.*, 1990, 1994, 1996; Heindel *et al.*, 1992, 1994; Field *et al.*, 1989; all as cited in USEPA, 2004b). Reproductive effects in males were noted in the subchronic and chronic studies described in the preceding paragraphs.

The EPA reference dose (RfD) for boron is 0.2 mg/kg/day (USEPA, 2004a) based on developmental effects in rats from two studies (Price *et al.*, 1996; Heindel *et al.*, 1992; both as cited in USEPA, 2004b). The RfD was derived using the benchmark dose (BMD) method (BMDL₀₅ from Allen *et al.*, 1996 as cited in USEPA, 2004b). EPA calculated the health reference level (HRL) of 1.4 mg/L or 1,400 µg/L for boron using the RfD of 0.2 mg/kg/day and a 20 percent screening relative source contribution.

EPA also evaluated whether health information is available regarding the potential effects on children and other sensitive populations. Studies in rats, mice, and rabbits identify the developing fetus as potentially sensitive to boron. Price *et al.* (1996 as cited in USEPA, 2004b) identified a “lowest-observed-adverse-effect level” (LOAEL) of 13.3 mg/kg-day and a “no-observed-adverse-effect level” (NOAEL) of 9.6 mg/kg-day in the developing fetus, based on decreased fetal body weight in rats. Accordingly, boron at concentrations greater than the HRL might have an effect on prenatal development. Individuals with severely impaired kidney function might also be sensitive to boron exposure since the kidney is the most important route for excretion.

3.3 Occurrence and Exposure

3.3.1 Use and Environmental Release

The major commercial uses of boron are in the production of glass and ceramics. According to the United States Geological Survey (USGS), in 2003 these industries accounted for 78 percent of U.S. consumption of boron compounds. The industries were primarily located in the North Central United States and Eastern United States. Soaps and detergents accounted for an additional 6 percent of U.S. consumption, agriculture accounted for 4 percent, fire retardants accounted for 3 percent, and other uses accounted for 9 percent (USGS, 2004). Experimental uses include recyclable sodium borohydride fuel for powering fuel cell vehicles (USGS, 2004). Borax and boric acid are used as a neutron absorber in atomic reactors; other miscellaneous uses of borates are found in cosmetics and leather tanning (ATSDR, 1992). Boron trichloride is used in the manufacture and purification of boron, for catalysis of organic reactions, in semiconductors, in purification of metal alloys, and in bonding of iron and steels. Boron trifluoride is used predominately in catalysis, but is also used as a fumigant, in metallurgy, and for neutron detection (Windholz *et al.*, 1983).

According to the website of Rio Tinto Borax, the largest commercial producer of borates, world demand for borates is distributed among the following major uses: insulation fiberglass, textile fiberglass, and heat-resistant glass account for 42 percent of world demand; ceramic tile bodies and ceramic and enamel frits and glazes account for 14 percent; detergents, soaps, and personal care products account for approximately 10 percent; agricultural micronutrients account for 7 percent; and other uses, including wood preservatives, flame retardants, and pest control products, account for 27 percent (Rio Tinto Borax, 2004).

The United States, Turkey, and Russia are the leading producers of boron compounds, followed by Argentina, Chile, and China (USGS, 2004). In 2003, Turkey produced the greatest quantity of ore, while the U.S. led in production of refined boron compounds. U.S. boron resources, mostly sediments and brines, are primarily located in California. U.S. production of boron compounds between 1999 and 2003 ranged between 518,000 metric tons and 618,000 metric tons (measured as boric oxide). In 2003, the U.S. imported approximately 174,000 metric tons of boron compounds and exported approximately 244,000 metric tons (USGS, 2004).

Environmental boron can have natural or anthropogenic sources. Boron is a naturally occurring compound, usually found in inorganic form in sediments and sedimentary rocks. Natural weathering of rocks is thought to be the primary source of boron compounds in water and soil (Butterwick *et al.*, 1989 as cited in ATSDR, 1992). Such weathering varies geographically, however. In the United States, the richest deposits are in California. Releases to air from oceans, volcanos, and geothermal steam are other natural sources of boron in the environment (Graedel, 1978 as cited in ATSDR, 1992). Global releases of elemental boron through weathering, volcanic, and geothermal processes are estimated at approximately 360,000 metric tons annually (Moore, 1991). Human causes of boron contamination include releases to air from power plants, chemical plants, and manufacturing facilities. Fertilizers, herbicides, and industrial wastes are among the sources of soil contamination. Contamination of water can come directly from industrial wastewater and municipal sewage, as well as indirectly from air

deposition and soil runoff (ATSDR, 1992). Borates in detergents, soaps, and personal care products can also contribute to the presence of boron in water.

Boric acid and its sodium salts are registered for use as pesticides. Data from the U.S. Bureau of Mines, cited in EPA's 1994 reregistration eligibility document for boron pesticides (USEPA, 1994a), suggest that approximately 293,000 pounds of boron minerals were used annually for "agricultural purposes" around 1990. In the reregistration eligibility document EPA stated that the amount of boron used specifically as pesticide is somewhat less than the amount used for agricultural purposes, and that boric acid use declined significantly during the 1980s (USEPA, 1994a).

Two anthropogenic boron compounds, boron trichloride and boron trifluoride, are listed as Toxics Release Inventory (TRI) chemicals. For a discussion of the nature and limitations of TRI data, see Chapter 2.

TRI data for boron trichloride (see Exhibit 3-2) are reported for the years 1995 to 2003 (USEPA, 2006). For boron trichloride, on-site air emissions constitute all of the total releases (on- and off-site), and these have generally fluctuated in the range of hundreds of pounds per year during the period of record. TRI releases for boron trichloride were reported from facilities in 6 States (Arizona, California, Indiana, New Mexico, Pennsylvania, and Wisconsin).

Exhibit 3-2: Environmental releases (in pounds) of boron trichloride in the United States, 1995-2003

Year	On-Site Releases				Off-Site Releases	Total On- & Off-site Releases
	Air Emissions	Surface Water Discharges ¹	Underground Injection	Releases to Land		
1995	5	-	0	0	0	5
1996	37	-	0	0	0	37
1997	754	0	0	0	0	754
1998	750	0	0	0	0	750
1999	350	-	0	0	0	350
2000	605	-	0	0	0	605
2001	626	0	0	0	0	626
2002	258	0	0	0	0	258
2003	5	-	0	0	0	5

¹ "-" denotes blank cells on reporting forms. "0" is entered when the reporting forms contained only zeros or "NA's".

Source: USEPA, 2006.

Boron trifluoride releases, also for the years 1995 to 2003 (see Exhibit 3-3), are similarly dominated by on-site air emissions. Boron trifluoride releases ranged in the tens of thousands of pounds annually. TRI releases for boron trifluoride were reported from facilities in 14 States (AL, AR, DE, FL, KY, LA, MD, NY, OH, OK, PA, SC, TN, and TX) (USEPA, 2006).

Exhibit 3-3: Environmental releases (in pounds) of boron trifluoride in the United States, 1995-2003

Year	On-Site Releases				Off-Site Releases	Total On- & Off-site Releases
	Air Emissions	Surface Water Discharges	Underground Injection	Releases to Land		
1995	25,019	0	0	0	929	25,948
1996	29,881	0	0	0	0	29,881
1997	21,290	0	0	0	5	21,295
1998	37,802	5	0	0	0	37,807
1999	16,725	0	0	0	0	16,725
2000	11,595	0	0	0	250	11,845
2001	11,496	0	0	0	0	11,496
2002	10,114	0	0	0	0	10,114
2003	7,513	0	0	0	4,295	11,808

Source: USEPA, 2006.

3.3.2 Ambient Water Occurrence

Ambient lakes, rivers, and aquifers are the source of most drinking water. Data on the occurrence of boron in ambient water, as well as biotic tissue and bed sediment, are available from the National Water Quality Assessment (NAWQA) program of the USGS. For more information on this program, see Chapter 2. The Minnesota Pollution Control Agency has also surveyed boron in ground water.

NAWQA

No national NAWQA data are available on the occurrence of boron in ambient waters. However, some regional data are available. Boron was among the analytes in USGS ground water monitoring in the Sacramento Valley in California in 1996 (Dawson, 2001) and the lower Illinois River Basin from 1984 to 1991 (Warner, 1999). Boron was also an analyte in NAWQA studies of bed sediments and/or fish tissues from the Tualatin River Basin of Oregon from 1992 and 1996 (Bonn, 1999), the Lower Snake River Basin of Idaho and Oregon in 1997 (Clark and Maret, 1998), and the Yellowstone River Basin in Montana, North Dakota, and Wyoming from 1976 to 1979 (Peterson and Zelt, 1999).

In ground water from the Sacramento Valley aquifer, boron was detected in all 31 samples, in concentrations ranging from 12 µg/L to 1,100 µg/L. The median concentration was 42 µg/L. Two of the 31 samples had concentrations in excess of the then-current Health Advisory Level of 600 µg/L (Dawson, 2001). (That lifetime Health Advisory Level was associated with an RfD of 0.09 mg/kg/day. In June 2004 EPA established the current RfD of 0.02 mg/kg/day.)

In the lower Illinois River Basin, 71 percent of ground water samples collected between 1984 and 1991 contained boron concentrations higher than the minimum reporting level for this study of 50 µg/L. The highest detected concentration was 2,100 µg/L. Higher boron concentrations were generally found in deeper and more ancient aquifers (Warner, 1999).

At a minimum reporting level of 0.2 µg/g dry weight, boron was detected in 100 percent of ten fish tissue samples from the Tualatin River Basin. The median concentration was 1.2 µg/g and the maximum concentration was 3.5 µg/g (Bonn, 1999).

At a minimum reporting level of 0.1 µg/g dry weight, boron was detected in most or all of 25 fish tissue samples from the Lower Snake River Basin, in concentrations as high as 1.8 µg/g (Clark and Maret, 1998).

At a reporting limit of 10 mg/kg, boron was detected in 98 percent of bed sediment samples in the Yellowstone River Basin. The median concentration was 28 mg/kg and the 95th percentile concentration was 57 mg/kg (Peterson and Zelt, 1999).

Minnesota Pollution Control Agency

As a baseline survey of ground water quality in the State, the Minnesota Pollution Control Agency took samples from 954 drinking water wells between 1992 and 1996. Seventy (8.7 percent of) samples had boron concentrations in excess of 600 µg/L, and another 25 samples had concentrations between 500 and 600 µg/L. High boron concentrations in Cretaceous, Precambrian, and buried Quaternary aquifers are likely due to the natural abundance of boron in the earth's crust. High boron concentrations in surficial Quaternary aquifers, on the other hand, are likely due to anthropogenic factors. The overall median concentration of boron was 46 µg/L (MPCA, 1998).

3.3.3 Drinking Water Occurrence

In the 1980s, EPA collected nationally representative data on boron occurrence in drinking water from public water systems served by ground water as part of the National Inorganics and Radionuclides Survey (NIRS). More recently, the American Water Works Association Research Foundation (AwwaRF) conducted a study of boron occurrence that included both ground water and surface water systems.

NIRS

Between 1984 and 1986, single samples were taken from 989 community public water systems (PWSs) under NIRS. Only systems served by ground water were included in the survey. Systems were selected to be geographically representative, and to include a representative distribution of system sizes. For more details on NIRS, see Chapter 2 and USEPA (2008).

Results of the survey are presented in Exhibit 3-4. Approximately 81.9 percent of groundwater PWSs had detections of boron (that is, concentrations at or above the minimum reporting level: \geq MRL, or \geq 0.005 mg/L). These detections affected about 88.1 % of the population served by the PWSs, equivalent to approximately 75.5 million people served by ground water nationally. Detections at a concentration greater than one-half the HRL ($> \frac{1}{2}$ HRL, or $>$ 0.7 mg/L) occurred in 4.3% of surveyed PWSs, affecting 2.9% of the population served, equivalent to approximately 2.5 million people nationally. Concentrations greater than the HRL ($>$ HRL, or $>$ 1.4 mg/L) were found in approximately 1.7% of surveyed PWSs,

affecting 0.4% of the population served, equivalent to approximately 0.4 million people nationally.

Exhibit 3-4: Summary NIRS Occurrence Statistics for Boron in Ground Water Systems

Frequency Factors	NIRS Data on Boron		National System & Population Numbers ¹
Total Number of Ground Water Samples/Systems	989		59,440
99 th Percentile Concentration (all samples)	2.44 mg/L		--
Health Reference Level (HRL)	1.4 mg/L		--
Minimum Reporting Level (MRL)	0.005 mg/L		--
Maximum Concentration of Detections	3.95 mg/L		--
99 th Percentile Concentration of Detections	2.6 mg/L		--
Median Concentration of Detections	0.047 mg/L		--
Total Population Served by Ground Water	1,482,153		85,681,696
Occurrence by Sample/System	Number	Percentage	National Extrapolation
Ground Water PWSs with Detections (\geq MRL) Range of NIRS States	810 0 - 74	81.9% 0 - 100%	48,682 N/A
Ground Water PWSs > 1/2 HRL Range of NIRS States	43 0 - 8	4.3% 0 - 37%	2,584 N/A
Ground Water PWSs > HRL Range of NIRS States	17 0 - 5	1.7% 0 - 26%	1,022 N/A
Occurrence by Population Served			
Population Served by GW PWSs with Detections Range of NIRS States	1,306,048 0 - 343,465	88.1% 0 - 100%	75,501,000 N/A
Population Served by GW PWSs > 1/2 HRL Range of NIRS States	42,702 0 - 20,465	2.9% 0 - 34%	2,469,000 N/A
Population Served by GW PWSs > HRL Range of NIRS States	6,443 0 - 2,500	0.4% 0 - 34%	372,000 N/A

1. Total PWS and population numbers are from EPA's March 2000 Water Industry Baseline Handbook, 2nd Edition. National extrapolations are generated by multiplying the system/population percentages and the national Baseline Handbook system/population numbers.

Abbreviations:

PWS = Public Water Systems; GW = Ground Water; N/A = Not Applicable; Total Number of Samples/Systems = total number of samples/systems on record for the contaminant; 99th Percentile Concentration = the concentration in the 99th percentile sample (out of either all samples or just samples with detections); Median Concentration of Detections = the concentration in the median sample (out of samples with detections); Total Population Served = the total population served by PWSs for which sampling results are available; Ground Water PWSs with Detections, PWSs > 1/2 HRL, or PWSs > HRL = GW PWSs with at least one sampling result greater than or equal to the MRL, exceeding the 1/2 HRL benchmark, or exceeding the HRL benchmark, respectively; Population Served by GW PWSs with Detections, by PWSs > 1/2 HRL, or by PWSs > HRL = population served by GW PWSs with at least one sampling result greater than or equal to the MRL, exceeding the 1/2 HRL benchmark, or exceeding the HRL benchmark, respectively.

Notes:

-Only results at or above the MRL were reported as detections. Concentrations below the MRL are considered non-detections.

AwwaRF Boron Study

Both ground water PWSs and surface water PWSs were included in a boron survey funded by the American Water Works Research Foundation (Frey *et al.*, 2004). The AwwaRF study recruited 189 PWSs representing 407 source waters in 41 States. Of the 407 source water sample kits distributed in 2003, approximately 342 were returned. Of these 342 samples, 341 were analyzed for boron. Approximately 67 percent (or 228) represented ground water sources and 33 percent (or 113) represented surface water sources. The samples were analyzed for boron with a method detection limit of 2.0 µg/L (Frey *et al.*, 2004).

Boron was detected with concentrations equal or greater than the method detection limit in 226 of 228 ground water samples (99.1%) and 110 of 113 surface water samples (97.3%). Boron concentrations greater than ½HRL, or >0.7 mg/L, were found in 20 of 228 ground water samples (8.8%) and no surface water samples (0%). Boron concentrations greater than the HRL, or >1.4 mg/L, were found in seven of 228 ground water samples (3.1%) and no surface water samples (0%). The seven HRL exceedances were found at five systems. The highest concentration detected in ground water was approximately 3.32 mg/L, and the highest concentration in surface water was 0.345 mg/L (Seidel, 2006). The median concentrations were 0.0514 mg/L in ground water and 0.029 mg/L in surface water (Frey *et al.*, 2004).

Although the survey was not statistically representative, it indicates some general trends. On the whole, boron contamination of surface water is less significant than contamination of ground water. No geographic trends were evident in ground water results, but surface water contamination appeared to be more prevalent in the Western U.S. than the Eastern U.S. Longitudinal sampling (i.e., sampling at multiple points along the path of water undergoing treatment) at 15 systems revealed that a wide variety of treatment techniques were largely ineffective at removing boron, so boron concentrations in source water (such as those collected in this study) are likely to be indicative of concentrations in finished water (Frey *et al.*, 2004).

Community Water System Survey (CWSS)

The 2000 Community Water System Survey (CWSS) (USEPA, 2002a; 2002b) gathered data on the financial and operating characteristics of a random sample of community water systems nationwide. In addition, the Survey asked all “very large” community water systems, those that serve more than 500,000 people (a total of 83 systems), to provide monitoring results for five regulated compounds (arsenic, atrazine, 2,4-D, simazine, and glyphosate) and four unregulated compounds (radon, methyl tertiary-butyl ether [MTBE], metolachlor, and boron), including results from raw water at each intake and from finished water at each treatment plant. EPA received completed questionnaires from 58 systems. However, not all systems answered every question. Note that because reported results are incomplete, they are more illustrative than statistically representative.

Results of raw water monitoring are aggregated by type of intake. In raw ground water, 34 observations of boron occurrence were reported. Among detects, the median concentration was 120 µg/L and the 90th percentile concentration was 273 µg/L. Non-detects were reported at 2.6 percent of ground water intakes. In raw surface water, 15 observations of boron occurrence were reported. Among detects, the median concentration was 59 µg/L and the 90th percentile

concentration was 180 µg/L. Non-detects were reported at 22.2 percent of surface water intakes (USEPA, 2002b).

Results of finished water monitoring are aggregated by system type. At systems primarily served by ground water, 5 observations of boron occurrence were reported. Among detects, the median concentration was 102 µg/L and the 90th percentile concentration was 234 µg/L. No non-detects were reported. At systems primarily served by surface water, 14 observations of boron occurrence were reported. Among detects, the median concentration was 56 µg/L and the 90th percentile concentration was 500 µg/L. Non-detects were reported at 9.1 percent of treatment plants. At systems primarily served by purchased water, 6 observations of boron occurrence were reported. Among detects, the median concentration was 164 µg/L and the 90th percentile concentration was 200 µg/L. Non-detects were reported at 1.8 percent of treatment plants (USEPA, 2002b).

3.4 Technology Assessment

3.4.1 Analytical Methods

Boron can be detected using EPA Method 200.7. Method 200.7 relies on inductively coupled plasma-atomic emission spectrometry (ICP-AES). A full description of EPA Method 200.7 can be found in EPA's *Methods for the Determination of Metals in Environmental Samples Supplement 1* (USEPA, 1994b). A brief summary of this method is provided below. It should be noted that the analytical result of this method is for the amount of elemental boron; the method does not identify the boron compound(s) present.

EPA Method 200.7

In EPA Method 200.7 (Revision 4.4), "*Determination of Metals and Trace Elements in Water and Wastes by ICP/Atomic Emission Spectrometry*," an aliquot of a well-mixed, acid-preserved aqueous sample is accurately transferred for sample processing. The sample is made up to one-half the original aliquot volume, mixed, and then allowed to settle overnight if the prepared aliquot contains undissolved material. Note that in low-turbidity water, boron determinations can be completed by "direct analysis" of acid-preserved samples. The analysis involves multielemental determinations by ICP-AES using sequential or simultaneous instruments. The instruments measure characteristic atomic-line emission spectra by optical spectrometry. Samples are nebulized and the resulting aerosol is transported to the plasma torch. Element-specific emission spectra are produced by a radio-frequency ICP. The spectra are dispersed by a grating spectrometer, and the intensities of the line spectra are monitored at specific wavelengths by a photosensitive device (USEPA, 1994b).

Note that boron samples can become contaminated by borosilicate glass. Only plastic or polytetrafluoroethylene (PTFE) labware should be used when collecting, storing, and handling water samples for boron analysis (USEPA, 1994b).

The method detection limit (MDL¹) for boron using Method 200.7 is reported to be 0.003 mg/L (USEPA, 1994b). The average recovery ranges from 97 to 98 percent depending on the spike concentration and whether tap or well water was used.

Another possible method for boron detection is Standard Method (SM) 4500-B B. The analytical range for this method is between 100 to 1,000 µg/L. This method, known as the Curcumin Method, is available in the 19th edition of *Standard Methods for the Examination of Water and Wastewater* (AWWA, 1995).

3.4.2 Treatment Technologies

Treatment technologies do not influence the determination of whether or not a contaminant should be regulated. However, before a contaminant can be regulated with a national primary drinking water regulation (NPDWR), treatment technologies must be readily available. There is no evidence that boron and boron compounds are significantly removed by conventional treatments, such as coagulation/flocculation, sedimentation, and inert media filtration. Two treatment technologies that may be appropriate are ion exchange and reverse osmosis.

Ion exchange involves the selective removal of charged inorganic species from water using an ion-specific resin. The surface of the ion exchange resin contains charged functional groups that hold ionic species by electrostatic attraction. As water passes by the resin, charged ions on the resin surface are exchanged for the contaminant species in the water. When all of the resin's available exchange sites have been replaced with ions from the feed water, the resin is exhausted and must be regenerated or replaced.

Wong (1984) evaluated eight technologies for their ability to remove boron from evaporator product water at power plants. Boron concentration in the evaporator-product water averaged 11 mg/L, and ranged as high as 38 mg/L. Only three technologies successfully reduced boron levels to below 0.3 mg/L. These were a boron-specific ion exchange resin, a process of coagulation, precipitation and filtration, and a strong-base anion-exchange resin. Wong dismissed the coagulation, filtration, and filtration process as unacceptable due to high chemical dosage requirements and high operating cost. Of the two ion exchange methods, Wong determined that the strong-base anion exchange resin would have lower regeneration costs, at least in the case of the evaporator product water, which is low in dissolved solids.

Reverse osmosis (RO) is similar to other membrane processes, such as ultrafiltration and nanofiltration, in that water passes through a semi-permeable membrane. However, in the case of RO, the membrane is non-porous. RO involves the use of applied hydraulic pressure to oppose the osmotic pressure across the membrane, forcing the water from the concentrated-

¹ The Method Detection Limit is a statistical estimate of the minimum concentration of a substance that can be measured and reported with 99 percent confidence that the analyte concentration is greater than zero, *i.e.*, greater than the background signal. The calculation of the MDL is based upon the precision of a series of replicate measurements of the analyte at low concentrations. The MDL incorporates estimates of the accuracy of the determination. The MDL is not a concentration that can typically be measured by the method on a routine basis. Detection limits may vary between analysts and laboratories under various laboratory conditions.

solution side to the dilute-solution side. The water dissolves into the membrane, diffuses across, then dissolves out into the permeate. Most inorganic and many organic contaminants are rejected by the membrane and will be retained in the concentrate.

Folster *et al.* (1980) tested hollow-fiber (HF) RO and spiral-wound (SW) RO in two separate treatment plants in New Mexico. At the treatment plant in San Jon, with influent boron levels of 0.75 mg/L, HF RO and SW RO removed 15 percent and 3 percent of boron, respectively. At Alamogordo, however, where influent concentrations were lower (0.09 mg/L), HF RO and SW RO were ineffective; in fact, boron concentrations rose to 0.14 mg/L and 0.13 mg/L, respectively. These findings suggest that the potential for RO use in boron treatment is limited.

3.5 Regulatory Determination

The Agency has made a determination not to regulate boron with a national primary drinking water regulation (NPDWR). While boron was found at levels greater than the HRL (and ½ the HRL) in several of the ground water systems surveyed by NIRS, it was not found at levels greater than the HRL (or ½ the HRL) in the surface waters sources evaluated in the AwwaRF study. Taking this surface water information into account, the Agency believes that the overall national occurrence and exposure from both surface and ground water systems together is likely to be lower than the values observed for the NIRS ground water data. Because boron is not likely to occur at levels of concern when considering both surface and ground waters systems, the Agency believes that an NPDWR does not present a meaningful opportunity for health risk reduction.

The Agency plans to update the Health Advisory for boron to provide more recent health information. The updated Health Advisory will provide information to any States with public water systems that may have boron above the HRL. If a State finds highly localized occurrence of boron at concentrations above the HRL, it should consider whether State-level guidance (or some other type of action) may be appropriate.

The Agency's regulatory determination for this contaminant is presented formally in the *Federal Register*.

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