

**Draft Screening Assessment**  
**Boric Acid, its Salts and its Precursors**

**Environment and Climate Change Canada**  
**Health Canada**

**July 2016**

## Synopsis

Pursuant to section 68 or section 74 of the *Canadian Environmental Protection Act, 1999* (CEPA), the Ministers of Environment and Climate Change and of Health have conducted a screening assessment of boric acid, its salts and its precursors as part of the Substance Groupings Initiative of Canada's Chemicals Management Plan (CMP). Substances in this assessment were identified as priorities for action, as they met categorization criteria under subsection 73(1) of CEPA or were included for assessment efficiency.

This screening assessment focuses on boric acid, and therefore includes boric acid, its salts and its precursors, i.e., boron-containing substances that release boric acid through all transformation pathways (e.g., hydrolytic, oxidative, digestive or metabolic) at environmentally or physiologically relevant conditions (i.e., pH and concentration). Boric acid, its salts and its precursors of commercial significance in Canada were considered in terms of their contribution to the combined exposure to boric acid but were not individually assessed. This assessment considers total exposure of humans and other living organisms to boric acid, whether it is present in environmental media (e.g., water, sediment, soil or air), food or products.

Boric acid has natural and anthropogenic sources. Natural sources of boric acid include sea-salt aerosols, soil dusts, volcanoes, biomass burning (e.g., forest fires), plant aerosols, and rock and soil weathering. Anthropogenic sources are also significant and include the manufacture, import and use of boric acid, its salts and its precursors in products and manufactured items. According to information reported under section 71 of CEPA for nine substances that were manufactured or imported above reporting thresholds in Canada in 2008 and information gathered by the Canada Border Services Agency (CBSA) (2009-2012), large quantities of boric acid, its salts and its precursors are imported annually into Canada (42 000–61 000 metric tons). The substances are used for a wide variety of products and applications, including fibreglass insulation, oil and gas extraction, fertilizers, cellulose insulation, gypsum boards, engineered wood products, pulp and paper manufacturing, rubber manufacturing, chemical manufacturing, metallurgical applications, cleaning products, cosmetics, drugs and natural health products (NHPs), swimming pool and spa chemicals, and surface finishing. Other anthropogenic sources include the incidental production and subsequent release of boric acid as a result of activities such as coal-fired power generation, metal mining (including base metals, precious metals and uranium), base metals and precious metals smelting and refining, coal mining, oil sands extraction and processing, oil and gas extraction, wastewater treatment (including the land application of biosolids), and waste disposal (landfill leachate).

Following releases to the environment, boric acid may enter water, air and soil media. Because of its high water solubility (49 grams per litre [g/L]), boric acid released to the aquatic environment is expected to remain in this compartment and to be highly bioavailable to aquatic organisms. Boric acid released to air is removed from the atmosphere and deposited to aquatic and terrestrial environments by wet (rain and

snow) and dry deposition. In soil, boric acid is considered highly mobile, because it does not undergo redox reactions and its bioavailability is mainly influenced by adsorption reactions that may occur slowly. Generally, boric acid is not considered bioaccumulative in most aquatic organisms and especially not in invertebrates and fish, although bioaccumulation has been observed in some aquatic plants and algae. Evidence suggests that boric acid does not biomagnify in the environment.

Boron, absorbed as boric acid is a micronutrient for plants and other organisms such as fish and frogs. Boric acid may be taken up by aquatic organisms, and has been demonstrated to cause harm at moderately low concentrations as indicated by a long-term chronic predicted no effect concentration (PNEC) value of 1.5 milligrams of boron per litre (mg B/L). Considering the high bioavailability of anthropogenic boric acid added in soil compared to natural sources of boron, the added-risk approach focusing on anthropogenic added fraction only was used to characterize the effects of boric acid on soil organisms. Although certain soil-dwelling organisms are sensitive to boric acid, it is generally anticipated to cause harm at moderately low concentrations as a result of chronic exposure (i.e., PNEC<sub>added</sub> value of 6.08 mg B per kilogram [kg]).

Ecological exposure scenarios were developed for the various activities that represent significant sources of release of boric acid, its salts and its precursors to the environment. Exposure to boric acid was assessed based on modelled and measured concentrations of total or dissolved boron in environmental media, subsequently used to derive predicted environmental concentrations (PECs). Substance-specific exposure scenarios were developed to represent releases of boric acid from uses associated with the following sectors and activities: pulp and paper manufacturing, “down-the-drain releases” from specific uses (e.g., soaps and detergents, cosmetics, swimming pool chemicals), rubber manufacturing, electroplating, fiberglass insulation manufacturing, cellulose insulation manufacturing, gypsum board manufacturing, engineered wood manufacturing and fertilizer manufacturing. In addition, exposure was assessed for the following sectors based on their potential to release boric acid incidentally (as a by-product): coal-fired power generation, metal mining, base and precious metals smelting and refining, coal mining, oil sands extraction and processing, and wastewater and wastes management. Risk quotient (RQ) analyses were performed comparing aquatic concentrations of dissolved or total boron to effect concentrations. RQs were generally low. However, based on the high leachability of boron in slags from certain precious metal recovery operations and high RQs for aquatic organisms identified in the vicinity of one facility from the metal mining sector, it is reasonable to assume that other facilities engaged in similar activities could release elevated concentrations of boric acid to the aquatic environment.

Considering all available lines of evidence presented in this draft screening assessment, there is risk of harm to organisms, but not to the broader integrity of the environment, from boric acid, its salts and its precursors. Therefore, it is proposed to conclude that boric acid, its salts and its precursors meet the criteria under paragraph 64(a) of CEPA as they are entering or may enter the environment in a quantity or concentration or under conditions that have or may have an immediate or long-term harmful effect on the

environment or its biological diversity. However, it is proposed to conclude that boric acid, its salts and its precursors do not meet the criteria under paragraph 64(b) of CEPA as they are not entering the environment in a quantity or concentration or under conditions that constitute or may constitute a danger to the environment on which life depends.

Boric acid, its salts and its precursors are considered to be toxicologically equivalent. Results from animal experiments demonstrate that boric acid adversely affects fertility, reproduction and development, and these adverse effects observed across species were very similar, both in nature and effective doses. A benchmark dose level (BMDL) of 2.90 mg B/kg of body weight per day (bw/d) for decreased testicular weight derived using two dog toxicity studies has previously been established as a point of departure by Health Canada. Additionally, a no observed adverse effect level (NOAEL) of 9.6 mg B/kg bw/d was noted in the rat for developmental effects. Given limitations in the available studies on humans, the effects noted in the animal studies were considered the critical effects for risk characterization.

Canadians are exposed to boric acid from environmental media, food, drinking water and products (this exposure was characterized through the use of biomonitoring data from Canadian and European studies). Total boron measured in blood in individuals provides a measure of integrated exposure for individuals, from all routes (oral, dermal, and inhalation) and all sources (including environmental media, food, and daily- or frequent-use products). Males have higher concentrations of boron in blood than females. For adults, there is a steady increase in the concentration of boron in blood with age; despite this trend in adults, blood boron concentrations are higher overall in children. Intake estimates from environmental media, food, drinking water and uses of certain product types were generated to characterize important sources of exposure. As boron is considered an essential micronutrient for plant growth, these estimates indicate, as expected, that naturally occurring boron in fruit, vegetables and to a lesser extent drinking water represent primary sources of exposure. Intake estimates from uses of boric acid in arts and craft materials, toys, cosmetics, cleaning products, NHPs, and swimming pool and spa products indicate that these may be significant sources of exposure to boric acid for the general population.

A comparison of estimates of intake predicted from biomonitoring data to critical effect levels in health effect studies results in margins of exposure that are potentially inadequate to address uncertainties in the exposure and health effects databases. Therefore, it is proposed to conclude that boric acid, its salts and its precursors meet the criteria under paragraph 64(c) of CEPA as they are entering or may enter the environment in a quantity or concentration or under conditions that constitute or may constitute a danger in Canada to human life or health.

## **Proposed Conclusion**

It is proposed to conclude that boric acid, its salts and its precursors meet one or more of the criteria set out in section 64 of CEPA.



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## 1. Introduction

Pursuant to section 68 or section 74 of the *Canadian Environmental Protection Act, 1999* (CEPA) (Canada 1999), the Minister of Environment and Climate Change and the Minister of Health conduct screening assessments of substances to determine whether these substances present or may present a risk to the environment or to human health.

The Substance Groupings Initiative is a key element of the Government of Canada's Chemicals Management Plan (CMP). Fourteen substances were identified as priorities for assessment, given that they met the categorization criteria under section 73 of CEPA. Subsequently, boron-containing substances that may transform into boric acid (i.e., boric acid precursors), with the exception of polymers, were included for assessment efficiency.

This screening assessment considers boric acid, its salts and its precursors. Boric acid salts and precursors are substances that contain boron and have the potential to dissociate, dissolve or degrade to release boric acid, at environmentally and physiologically relevant conditions (i.e., pH and concentration). It is recognized that combined exposure of humans and other organisms to boric acid may occur from different pathways and sources. Exposure to boric acid may occur due to anthropogenic activities involving boron-containing substances, as well as incidental production and ambient background concentrations of boron. For the purposes of the human health assessment, "boric acid" will refer to boric acid, its salts and precursors; where relevant, specific substances containing boron will be explicitly identified by name or Chemical Abstracts Service Registry Number (CAS RN). For ease of comparison of the different sources of boric acid, all concentrations and doses described in this document have been adjusted to give amounts of boron in its elemental form.

Screening assessments focus on information critical to determining whether substances meet the criteria as set out in section 64 of CEPA, by examining scientific information to develop conclusions by incorporating a weight of evidence approach and precaution.<sup>1</sup>

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<sup>1</sup> A determination of whether one or more of the criteria in section 64 are met is based upon an assessment of potential risks to the environment and/or human health associated with exposures in the general environment. For humans, this includes, but is not limited to, exposures from ambient and indoor air, drinking water, foodstuffs and the use of consumer products. A conclusion under CEPA is not relevant to, nor does it preclude, an assessment against the hazard criteria specified in the *Hazardous Products Regulations* which is part of the regulatory framework for the Workplace Hazardous Materials Information System for products intended for workplace use. Similarly, a conclusion based on the criteria contained in section 64 of CEPA does not preclude actions being taken under other sections of CEPA or other Acts.

This draft screening assessment includes consideration of information on chemical properties, environmental fate, hazards, uses and exposure, including additional information submitted by stakeholders. Relevant data were identified up to March 2016. Empirical data from key studies as well as some results from models were used to reach proposed conclusions. When available and relevant, information presented in assessments from other jurisdictions was considered.

The assessment does not represent an exhaustive or critical review of all available data. Rather, it presents the most critical studies and lines of evidence pertinent to the proposed conclusion. Additional information used for this assessment is summarized separately in supporting documentation as referenced in the assessment below, which is available upon request.

This draft screening assessment was prepared by staff in the Existing Substances programs at Health Canada and Environment and Climate Change Canada, and incorporates input from other programs within these departments. The ecological and human health portions of this assessment have undergone external written peer review and/or consultation. Comments on the technical portions relevant to human health were received from Dr. Eric Hooker and Dr. Katherine Super, TetraTech Inc., and comments related to the relationship between blood boron concentrations and intake were received from Michael Dourson, Toxicology Excellence for Risk Assessment and Sean Hays, Summit Toxicology. Comments on the technical portions relevant to the environment were received from Dr. M.C. Harrass and from Dr. L Kaputska, LK Consultancy. Although external comments were taken into consideration, the final content and outcome of the screening assessment remain the responsibility of Health Canada and Environment and Climate Change Canada.

The critical information and considerations upon which the draft screening assessment is based are provided in this document.

## 2. Scope of the Assessment

This screening assessment focuses on boric acid, its salts and its precursors. There are many different salts of boric acid that dissociate to boric acid. There are also many substances that release boric acid as a result of relevant transformation pathways (e.g., hydrolytic, oxidative, digestive or metabolic) at environmentally or physiologically relevant conditions (i.e., pH and concentration); these are considered to be precursors of boric acid. Boron-containing substances other than polymers, were evaluated for their potential to be precursors of boric acid (see Appendix A). Precursors of boric acid include the following groups of boron-containing substances: oxygen compounds of boron (including boric acids, borates or boric acid salts and borate esters), boron halides, boranes (borohydrides) and organo-boron compounds. Not all boron-containing substances are precursors of boric acid; notable exceptions include elemental boron, borides (such as boron nitride or carbide) and inert substances (e.g., sodium borate silicates or borosilicate glass), which therefore fall outside the scope of this assessment.

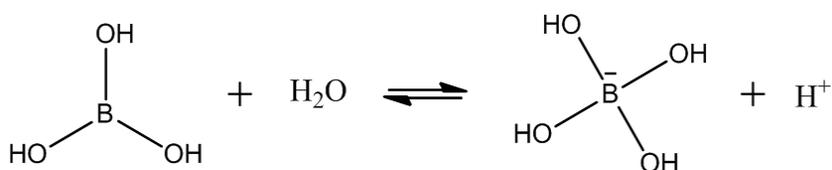
This assessment considers the combined exposure of humans and other organisms from different pathways and sources of boric acid. The presence of boric acid in environmental media, food or products may result from natural or anthropogenic sources. Anthropogenic sources of boric acid include incidental production and release (i.e., as a by-product) of boric acid and its precursors as well as the import and use of these substances, and products or manufactured items containing these substances. Boric acid precursors of commercial significance in Canada were considered in terms of their contribution to the combined exposure of boric acid, but were not individually assessed. Where feasible, background or reference levels were differentiated from levels attributed to anthropogenic sources.

Measurements of boric acid in environmental media, products and humans are generally expressed in terms of boron (B) content, corresponding to a fraction (i.e., 17.5%) of the mass of boric acid on a molecular weight basis. Boron-containing substances that are precursors of boric acid under environmentally and physiologically relevant conditions and concentrations are toxicologically equivalent to boric acid. Therefore, concentrations and doses of boric acid reported in this assessment are expressed as the mass of boron per volume or mass of media, and environmental concentrations of boric acid are also generally reported in this manner. This assessment only considers effects associated with boric acid, and does not address other elements or moieties that may be present in certain complex boron-containing substances that may release these other elements or moieties (such as ammonium, cobalt, lithium, silver or zinc). These other elements or moieties may be addressed or may have already been addressed via other CMP initiatives.

Engineered nanomaterials containing boron or boron-containing substances were not explicitly considered in exposure scenarios of this assessment. However, measured boron concentrations could include boron-containing nanomaterials or other boron-containing substances.

### 3. Substance Identity and Physical and Chemical Properties

Because of its high ionization potential, the metalloid boron does not form  $B^{3+}$  cations, but covalently bonds with electronegative atoms (Cotton and Wilkinson 1999). It has a high affinity for oxygen and forms strong covalent boron-oxygen bonds (Ball et al. 2012). Therefore, it mainly exists in the environment as boric acid. Boric acid is a Lewis acid, which, unlike a Brønsted-Lowry acid, accepts hydroxide ions instead of releasing protons. The structure is displayed on the left side of the equation in Figure 3-1. In dilute solutions ( $\leq 0.025M$ , or  $\sim 0.27$  g B/L) (IPCS 1998), which encompasses the environmentally and physiologically likely range, boric acid is in equilibrium with the borate anion ( $B(OH)_4^-$ ). However, based on the acid dissociation constant ( $pK_a$ ) value of 9.0 at  $25^\circ C$ , boric acid will predominantly exist in its neutral, undissociated form at environmentally and physiologically relevant pH values (5–8).



**Figure 3-1: Aqueous equilibrium of boric acid with the borate anion ( $B(OH)_4^-$ ),  $pK_a = 9.0$  at  $25^\circ C$**

Physical and chemical properties determine the overall characteristics of a substance, and play an important role in determining the environmental fate of substances as well as their toxicity to humans and non-human organisms.

Properties such as water solubility and acid dissociation constant ( $K_a$ ) are particularly relevant to the environmental fate and ecotoxicity of boric acid (Table 3-1), because they provide information on its bioavailability. Partition coefficients for boric acid (expressed as boron equivalent) pertaining to its partitioning between soil and water ( $K_{sw}$ ) and suspended particles and water ( $K_{spw}$ ) are discussed in Section 7.

**Table 3-1: Experimental physical and chemical property values for boric acid**

Property	Range of values ( <i>temperature</i> )	Representative value ( <i>temperature</i> )	Key reference(s)
Physical state	-	White odourless crystalline solid	Borax Europe 2012
Density ( $\text{kg/m}^3$ )	1435–1510 ( $15\text{--}23^\circ C$ )	1490 ( $23^\circ C$ )	Borax Europe 2012; IPCS 1998; ECHA 2007-2014
Vapour pressure (Pa)	Generally considered negligible	$9.9 \times 10^{-5}$	Borax Europe 2012

Property	Range of values ( <i>temperature</i> )	Representative value ( <i>temperature</i> )	Key reference(s)
Water solubility (g/L)	47.2–63.5 (20–30°C)	49.2 (25°C)	ATSDR 2010; Borax Europe 2012; IPCS 1998; ECHA 2007-2014
Log K <sub>ow</sub> (dimensionless)	-1.09–(-)0.757	-1.09 (22°C)	Borax Europe 2012; ECHA 2007-2014
pK <sub>a</sub> (dimensionless)	8.94–9.42 (20–25°C)	9.2 (25°C)	ATSDR 2010; Borax Europe 2012; IPCS 1998; ECHA 2007-2014

Abbreviations: K<sub>ow</sub>, octanol–water partition coefficient; pK<sub>a</sub>, acid dissociation constant

Boric acid is considered highly soluble in water, with an extremely low log K<sub>ow</sub> (Table 3-1.). Pure boric acid is not volatile, as indicated by its low vapour pressure ( $9.9 \times 10^{-5}$  Pa). Boric acid can be volatilized with steam from heated aqueous solutions (due to its dissolution into steam), or sublimed by high temperature processes (Ball et al. 2012; Schubert and Brotherton 2006). When heated, boric acid releases water in a stepwise fashion, forming various phases of metaboric acid (HBO<sub>2</sub>) as temperature increases, and eventually boron oxide (B<sub>2</sub>O<sub>3</sub>) (Cotton and Wilkinson 1999). Gaseous metaboric acid species are formed by the equilibration of water vapour with molten boron oxide at 600–1000°C (Schubert and Brotherton 2006).

## 4. Sources

### 4.1 Natural sources

Boron is a naturally occurring element in the terrestrial crust, with a concentration in the upper continental crust of approximately 10 mg/kg (Gupta 1993). Boron is not naturally found in its elemental form, but rather in the form of borosilicate minerals (the most abundant of which is tourmaline), boric acid or borates (Cotton and Wilkinson 1999; Holleman and Wiberg 2001). In the oceans, the average concentration of boron has been reported to be 4.5 mg B/L. Borate aerosols formed in the atmosphere via co-evaporation of boric acid with seawater, or the incursion of seawater into freshwaters, may be a significant source of boron in coastal areas (Argust 1998; Jahiruddin et al. 1998; Parks and Edwards 2005).

Global natural emissions to the atmosphere have been estimated to range between  $1.1 \times 10^9$  and  $3.1 \times 10^9$  kg B/year (Park and Schlesinger 2002). The main sources include sea-salt aerosols, soil dusts, volcanoes, biomass burning (e.g., forest fires) and plant aerosols. Atmospheric boron exists as gaseous or particulate boric acid, and may subsequently be introduced into surface water and soil as a result of wet and dry deposition. Naturally occurring boron is present in groundwater primarily as a result of leaching from rocks and soils containing borates and borosilicates WHO (2009). Rock and soil weathering constitute another important source of boron to the environment,

estimated at  $0.19 \times 10^9$  kg B/year (Park and Schlesinger 2002). The introduction of boron into surface water and soil as a result of these natural processes is reflected in the geochemical background concentrations in these media. Background concentrations are considered in this assessment (Section 8.3 and subsection 9.2.1) when estimating the exposure of ecological receptors and humans to boron substances.

## **4.2 Anthropogenic sources**

### **4.2.1 Manufacture of boric acid precursors**

There are no commercially valuable deposits of boron-containing minerals (i.e., borax, kernite, colemanite and ulexite) in Canada, with most mining activity taking place in the United States and Turkey and to a lesser degree in Chile, Argentina, Russia and Peru (USGS 2015). Furthermore, no evidence of the refinement of boron-containing minerals to other boric acid precursors was identified in Canada. Thus, for the purposes of this screening assessment, the term “manufacture” generally refers to incidental production, as described in the definition used by the National Pollutant Release Inventory (NPRI) of Environment and Climate Change Canada (NPRI 2014).

### **4.2.2 Import of boric acid precursors**

Information regarding the import of boric acid was acquired through a notice issued pursuant to section 71 of CEPA (Canada 2009), through data obtained from the Canada Border Services Agency (CBSA) (CBSA 2013), and from voluntary data submissions received from stakeholders.

The DSL Inventory Update (DSL IU) Phase 1 initiative that was launched in 2009 (Canada 2009) (for the reporting year 2008) included two boric acids and seven boric acid precursors that fall under the scope of this assessment (see Table A-1 in Appendix A). The survey collected information on quantities of substances imported into Canada, and aided in the identification of key uses and sectors of interest for these substances. Additionally, a request was made to the CBSA to obtain information on the import activity of boric acid and boric acid precursors captured within Harmonized System (HS) codes for the years 2009–2012 on a company-by-company basis. Twelve HS codes (10-digit) were identified that correspond to boric acid and boric acid precursors; these codes and the corresponding total annual import quantities (Table 4-1) were obtained from the CBSA (2013). In addition, voluntary submissions were received from a number of stakeholders to determine quantities and uses of boric acid and its precursors in commerce in Canada and to provide other information relevant to exposure characterization.

High-level aggregation of the quantity of boric acid and its precursors imported into Canada over the period 2009–2012 was tallied (Table 4-1) (CBSA 2013) (further detail on quantities of boric acid precursors imported into Canada is available in Environment Canada 2014a). Results from CBSA (2013) indicate that the categories “oxides of boron and boric acid” and “disodium tetraborate – other hydrates” represented 70–91.5% of boric acid imported into Canada from 2009–2012. Only one substance captured within

these HS codes, boron oxide (CAS RN 1303-86-2), has a boron content (31.1%) greater than boric acid (17.5%). However, based on results from the DSL IU Phase 1 survey of import quantities into Canada in 2008 and uses worldwide, quantities of boron oxide in commerce are much lower than those of boric acid (Ball et al. 2012; Environment Canada 2009a). Given that compounds of most commercial importance (e.g., borax pentahydrate and borax decahydrate) have boron contents lower than 17.5%, boron and other boric acid precursors corresponding to the other HS codes have boron contents on the order of, or lower than, that of boric acid. Therefore, the total import quantities recorded by the CBSA were assumed to correspond to boric acid for the purposes of calculating boron equivalents, thus simplifying the exposure characterization, while being a conservative assumption. Based on this assumption, between 42 000 000 and 61 000 000 kg of boric acid, approximately, were imported annually into Canada from 2009–2012.

**Table 4-1: Annual aggregate quantities of boric acid imported into Canada from 2009–2012 (CBSA 2013)**

HS code name <sup>A</sup>	HS code numbers	Quantity imported per year (kg) from 2009–2012
Oxides of boron and boric acid	2810000000, 2810000010, 2810000020	6 000 000–25 000 000
Disodium tetraborate – other hydrates	2840190000	26 000 000–31 000 000
Disodium tetraborate – anhydrous	2840110000	400 000–650 000
Natural borates and concentrates	2528000000, 2528100000, 2528900000	1 500 000–13 000 000
Other borates, peroxo-borates of metals	2840200000, 2840300090	1 500 000–4 500 000
Peroxo-borate (perborates)	2840300000, 2840300010	50 000–200 000
<b>Total<sup>B</sup></b>		<b>42 000 000–61 000 000</b>

<sup>A</sup> The Harmonized Commodity Description and Coding System is an international goods classification system developed by the Customs Co-operation Council (now the World Customs Organization) and used by Canada to classify imported and exported goods (<http://www.cbsa-asfc.gc.ca/trade-commerce/tariff-tarif/hcdcs-hsdcm/menu-eng.html>).

<sup>B</sup> The quantities reported originate from multiple substances that may contain variable amounts of boron (5–31%) based on their chemical formula.

### 4.2.3 Incidental manufacture of boric acid precursors

As noted in section 4.2.1, for the purpose of this assessment, the term “manufacture” also includes the incidental production of boric acid at any level of concentration as a

result of the manufacturing, processing or other uses of other substances, mixtures or products. Therefore, sectors that may incidentally produce boric acid as a result of their activities and generate releases to the environment are considered in this draft screening assessment.

Information regarding the incidental manufacture of boric acid was also acquired through a notice issued pursuant to section 71 of CEPA (Canada 2009). Results of this survey identified a number of coal-fired power plants as incidental manufacturers of boron oxide (CAS RN 1303-86-2; Environment Canada 2009a), a substance known to transform into boric acid.

A number of sectors have been identified as potential incidental sources of boric acid to the environment (air, water, soil or sediment): coal-fired power generation, metal mining (including base metals, precious metals and uranium), base and precious metals smelting and refining, coal mining, oil sands extraction and processing, oil and gas extraction, pulp and paper manufacturing, and waste and wastewater management. Further details regarding some of these sectors are available in Environment Canada (2014b, 2014c, 2014d, 2014e, 2014f, 2014g). Other potential sources include iron and steel manufacturing, aluminium smelting and cement production (Environment Canada 2013a). Detailed exposure scenarios leading to predicted concentrations of boron in the environment are discussed later in this report (Section 8-3) for the sectors with the greatest expected releases of boric acid.

## 5. Uses

Consumption of boron minerals and chemicals worldwide is distributed among the following major uses: glass products and ceramics (72%), soaps and detergents (0.9%), flame retardants (0.9%) and a large number of uses that represent the remaining 26.2% (CEH 2011). Boron compounds are used extensively in a wide range of industrial applications, almost all of which involve boron-oxygen compounds (Schubert 2003) that are boric acid precursors. More than 140 different types of end-use applications are reported for borates (EU 2007a). Major uses also include fibreglass insulation, agricultural products (fertilizers and pest control products), cellulose insulation, cleaning products (soaps and detergents, as well as cleaning, polishing and toilet preparations), basic pharmaceutical products and preparations, various chemicals and chemical products (e.g., chemicals for metallurgy, antifreeze, brake fluids, buffers and lubricants), gypsum board and wood products (veneer and engineered wood), paper and paper products, and flame retardants (RPA 2008; Ball et al. 2012).

In Canada, the major uses of boric acid, and the sectors where use occurs, were identified as a result of the DSL IU for 2008, CBSA import data for 2009–2012, and other stakeholder engagement activities (Environment Canada 2009a, 2013b; CBSA 2013). Importers identified through the CBSA were attributed to a sector based on publicly available information regarding the importer's primary activity, or by correlating the companies' activity with information obtained through DSL IU submissions or voluntary stakeholder engagement. As a result, the major uses and sectors implicated

in Canada include: cellulose and fibreglass insulation manufacturing, industrial and consumer cleaning products, personal care products, other chemicals (water softeners and swimming pool chemicals), gypsum board manufacturing, engineered wood products manufacturing, oil and gas extraction (e.g., hydraulic fracturing fluids), agriculture (fertilizers), pulp and paper manufacturing and packaging, rubber manufacturing, chemical manufacturing (e.g., lubricants), metallurgical applications (e.g., slag stabilization and analytical chemicals), and surface finishing (e.g., the cleaner and buffer in electroplating). Further detail is available in Environment Canada (2014a). For the purpose of this document, a personal care product is defined as a substance or mixture of substances that is/are generally recognized by the public for use in daily cleansing or grooming. Depending on both how the product is represented for sale and its composition, personal care products may fall into one of three regulatory categories in Canada: cosmetics, drugs or natural health products (NHPs).

The use of boric acid in NHPs, drugs, cosmetics, pest control products, fertilizers, and toys is regulated in Canada. For commercially available children's toys, compliance and enforcement of the existing prohibition on boron will continue as a part of the regular enforcement of the *Toys Regulations* under the *Canada Consumer Product Safety Act*. With respect to NHPs, the use of boric acid, its salts and its precursors in such products is regulated under the *Natural Health Products Regulations* and *Food and Drugs Act* (Canada 1985a, 2003). Boron compounds are present as medicinal ingredients and non-medicinal ingredients in currently licensed NHPs (LNHPD 2013). The Natural and Non-prescription Health Products Directorate's (NNHPD's) Multi-vitamin/Mineral Supplements monograph outlines the following source materials for boron in NHPs: boracic acid/orthoboric acid, borax/disodium tetraborate/sodium baborate/sodium borate/sodium pyroborate/sodium tetraborate, boron aspartate, boron citrate, boron glycinate, boron hydrolyzed animal protein (HAP) chelate, boron hydrolyzed vegetable protein (HVP) chelate, calcium borate/calcium pyroborate/calcium tetraborate, calcium borogluconate/calcium diborogluconate, calcium fructoborate and magnesium borate; whereas the Natural Health Products Ingredients Database lists borax, boric acid, boron aspartate, boron citrate, boron-enriched yeast, boron glycinate, boron HAP chelate, boron HVP chelate, calcium borate, calcium borogluconate, calcium fructoborate, lignite, magnesium borate and sodium borate as source ingredients for boron (Health Canada 2007a, 2007b; NHPID 2014).

In 2007, the NNHPD published the document *Boron as a Medicinal Ingredient in Oral Natural Health Products*, which evaluates the risks and benefits associated with the use of boron as a medicinal ingredient in oral NHPs, setting a maximum limit in multi-vitamin/mineral supplements of 700 micrograms per day ( $\mu\text{g}/\text{d}$ ), for adults only (Health Canada 2007b). A maximum daily dose of 3.36 mg B/d was set for products making bone mineralization-type claims associated not with the presence of boron but rather with other medicinal ingredients (e.g., vitamin D and calcium) (Health Canada 2007b). This higher maximum daily dose as compared to that for multi-vitamin/mineral supplements was based on the expectation that these types of products, with claims that are more therapeutic in nature, would be intended for older adults and that these products would be labelled as contraindicated for pregnant and breastfeeding women

and as advising consultation with a health care practitioner prior to use in the case of an estrogen-dependent cancer (Health Canada 2007b).

Boron compounds are also listed in the Drug Product Database as being found in human and veterinary drugs. For human drugs, it is used primarily as an ingredient in ophthalmic products and contact lens disinfectants, and otic and topical products; and it is used in the form of injectable solutions for veterinary drugs (DPD 2014). Under the *Food and Drugs Act, Food and Drugs Regulations* (Part C, Drugs, subsection c.01.028 b), drugs containing boric acid or sodium borate as a medicinal ingredient shall carry a cautionary statement to the effect that the drug should not be administered to a child under three years of age (Canada 1978, 1985a).

Boric acid, its salts and its precursors are used as ingredients in many cosmetics notified to Health Canada under the *Cosmetic Regulations* of the *Food and Drugs Act* (2012 email from the Consumer Product Safety Directorate, Health Canada, to the Existing Substances Risk Assessment Bureau, Health Canada; unreferenced). They are present in a wide variety of cosmetic products and are most common in skin lotion/moisturizer and skin cleanser products. Boric acid and its salts are included on the List of Prohibited and Restricted Cosmetic Ingredients (more commonly referred to as the Cosmetic Ingredient Hotlist or simply the Hotlist), an administrative tool that Health Canada uses to communicate to manufacturers and others that products containing certain substances are unlikely to be classified as a cosmetic under the *Food and Drugs Act*, and that certain substances, when present in a cosmetic at certain concentrations, may contravene the general prohibition found in section 16 of the *Food and Drugs Act* or a provision of the *Cosmetic Regulations* (Canada 2014; Health Canada 2014a). The current listing for boric acid and its salts does not include all precursors of boric acid and it describes a concentration limit of 5% for boric acid and its salts (CAS RN 10043-35-3 and 11113-50-1, including sodium borate 1303-96-4). Under the *Cosmetic Regulations*, the label of cosmetics (containing boric acid and its salts) are required to carry cautionary statements to this effect: "Do not use on broken or abraded skin. Not to be used by children under three years of age." A warning is not required when boric acid is used as a pH adjuster and the concentration is equal to or less than 0.1%. Other boric acid precursors are described in Hotlist entries: phenyl mercuric borate is described as prohibited in cosmetics; and sodium perborate, a peroxide-generating compound, is subject to data submission and cautionary label statements associated with peroxide-generating compounds.

In Canada, several boric acid salts and precursors, including boric acid, borax (pentahydrate), borax (disodium tetraborate decahydrate), disodium octaborate tetrahydrate and zinc borate, are active ingredients in pest control products. The use of boric acid and its salts as a pesticide is regulated under the *Pest Control Products Act* (Canada 2002). Health Canada's Pest Management Regulatory Agency [PMRA] has published a proposed re-evaluation decision for boric acid and its salts (Health Canada 2012). Boric acid salts and precursors are present in products used to control a broad range of insects and fungi in structures, wood and wood products including antisapstain, joinery and millwork applications, remedial wood preservation, and cockroach and ant

control products. As well, boric acid salts and precursors are registered for use as a wood composite preservative and material preservative for the manufacturing of paints, coatings, plastics and rubber (Health Canada 2012). In addition, borax, disodium tetraborate, boric acid, boric acid disodium salt pentahydrate and sodium borohydrate are included on the PMRA list of formulants as List 3 formulants and thus may be present in other pest control products (Health Canada 2010). For example, some algacide and sanitizer pool products regulated under the *Pest Control Products Act* contain boron as a formulant, which, when used according to label directions, results in a final concentration range in pool/spa water of 5 parts per trillion (ppt) to 1 part per million (ppm), depending on the use.

Boron is a recognized plant micronutrient and is regulated as a fertilizer under the *Fertilizers Act* (Canada 1985b). Boric acid, borax, sodium calcium borate (ulexite), calcium borate, sodium calcium borate, sodium pentaborate, boron polyamide and ammonium polyborate are all boron-containing substances in registered agricultural products. Approximately 80 registered agricultural products contain boron-containing substances in Canada (2012 email from the Fertilizer Program, Canadian Food Inspection Agency to Risk Management Bureau, Health Canada; unreferenced).

In Canada, boric acid and salts of boric acid in toys are specifically regulated under section 22 of the *Toys Regulations* of the *Canada Consumer Product Safety Act* (Canada 2010, 2011). A toy must not contain boric acid and salts of boric acid if they could, under reasonably foreseeable circumstances, become accessible to a child or, if they are used as a filling, could be released upon breakage or leakage. In 1997, Health Canada published a hazard assessment of boric acid in toys (Craan et al. 1997). For commercially available children's toys, compliance and enforcement of the existing prohibition on boron will continue as a part of the regular enforcement of the *Toys Regulations* under the *Canada Consumer Product Safety Act*.

Boric acid, its salts and its precursors are present in food packaging materials, including as a component of adhesives, paper and paperboard food packaging materials, and in flocculants/retention aids that are used in the production of paper. Boron is used as an additive in ethylene-vinyl acetate-vinyl alcohol copolymers (EVOH) and poly(ethylene/methacrylic acid) resin as a component of alkyd systems (level of < 7.5%) and epoxy primers (level of < 23%) in coatings for food plants on non-food contact surfaces (2013 email from Food Directorate to Risk Management Bureau, Health Canada, unreferenced).

## **6. Releases to the Environment**

### **6.1 Releases to air**

Co-evaporation of boric acid from industrial process waters at sufficiently high temperatures is anticipated, and is dependent on the amount of boron in the process water (Parks and Edwards 2005). Additional anthropogenic sources of boric acid and its precursors to air include the combustion of fossil fuels (especially coal), the manufacture of fibreglass and glass, and most metallurgical processes (Environment

Canada 2013a; Eriksson et al. 1981; Goodarzi 2013; Sakata et al. 2010; Temple et al. 1978; Van Limpt 2007). Emissions to air of boric acid are generally in gaseous and particulate forms of boron oxide, metaboric acid or boron halides that further transform into boric acid (Environment Canada 2009a; Park and Schlesinger 2002; Van Limpt 2007). Windblown particulate matter (PM) from dry tailings (from coal mining or oil sands extraction and processing) or ash piles from coal combustion may be a potential atmospheric source of boric acid (Environment Canada 2014b, 2014e, 2014f).

## **6.2 Releases to water and sediments**

Boric acid releases to water may include (but are not limited to) releases from coal-fired power plants (ash ponds and power plant effluents), oil sands extraction and processing (tailing ponds seepage and run-off to surface waters), coal mining (run-off to surface waters and seepage from tailing ponds), oil and gas extraction (leaks and spills), pulp and paper mills (effluent and landfill leachate), wastewater treatment systems<sup>2</sup> (effluent) and landfills (leachate), metal mining and base metals smelters (effluents), agricultural run-off to surface waters, surface finishing (effluent), rubber products manufacturing (effluent), and building products manufacturing (e.g., effluent from gypsum board, fibreglass insulation and wood products manufacturing facilities) (Environment Canada 2014a, 2014b, 2014c, 2014d, 2014e, 2014f, 2014g, 2014h).

## **6.3 Releases to soil**

Dry and wet deposition of atmospheric boric acid originating from anthropogenic air emissions and the application of biosolids are potential sources of boric acid to soil.

# **7. Environmental Fate and Behaviour**

## **7.1 Environmental distribution**

### **7.1.1 Air**

Based on the non-volatility of boric acid (due to negligible vapour pressure), it is expected to be emitted to air principally in PM. However, using an impregnated filter sampling technique, Fogg and Duce (1985) estimated that gaseous boron may represent up to 95% of total boron measured in air, and hypothesized the dominant chemical form to be boric acid. Residence times of 19–36 days and 2–6 days for gaseous and particulate boric acid, respectively, were calculated. A second study

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<sup>2</sup> In this assessment, the term “wastewater treatment system” refers to a system that collects domestic, commercial and/or institutional household sewage and possibly industrial wastewater (following discharge to the sewer), typically for treatment and eventual discharge to the environment. Unless otherwise stated, the term wastewater treatment system makes no distinction of ownership or operator type (municipal, provincial, federal, indigenous, private, partnerships). Systems located at industrial operations and specifically designed to treat industrial effluents will be identified by the terms “on-site wastewater treatment systems” and/or “industrial wastewater treatment systems”.

conducted by Anderson et al. (1994) using a similar sampling protocol also found high percentages of gaseous boric acid in the atmosphere versus particulate boric acid. The two sampling techniques involved the use of KOH-impregnated cellulose filters for the capture of smaller particles, molecular aggregates, or gases collectively referred to as gaseous boric acid. Since the size of suspended particles in the atmosphere ranges from 0.002–100 microns ( $\mu\text{m}$ ), approximately (Baird 1999), these studies could have overestimated the percentage of gaseous boric acid compared to the percentage of boric acid adsorbed to suspended particles or dissolved in atmospheric condensed phases. Flue gas measurements taken in a full-scale coal combustion process equipped with selective catalytic reduction (SCR), an electrostatic precipitator (ESP) and flue-gas desulphurization (FGD) showed vapour- and particulate-phases boron concentrations to be comparable (within one order of magnitude) prior to reaching pollution control systems (Cheng et al. 2009). It is expected that gaseous-phase boric acid as well as particulate boric acid emitted to the atmosphere will travel for a certain distance but will be removed from the atmosphere and deposited to terrestrial or aquatic environments by wet (rain and snow) and dry deposition (Anderson et al. 1994; Fogg and Duce 1985; Kot 2009; Zhao and Liu 2010).

### 7.1.2 Water and sediment

Generally, if released to water, most boric acid is expected to remain in the water column, where it is considered highly mobile, given its high water solubility (47.2–63.5 g B/L) (see section 3). At environmentally and physiologically relevant concentrations, boric acid  $[\text{B}(\text{OH})_3]$  is in a pH-dependent equilibrium with borate anions  $[\text{B}(\text{OH})_4^-]$  (CCME 2009). At acidic pH, undissociated boric acid is the predominant species, whereas at alkaline pH (i.e., above the  $\text{pK}_a$  of 9.0) the borate anion is predominant (Howe 1998; Parks and Edwards 2005). Both species are highly soluble and stable, because they do not undergo oxido-reduction reactions or biotransformation (Kot 2009). In natural waters (pH 6–8), polyborates and other minor complexes with transitional metals and fluoride may also exist (Basset 1980; Kot 2009). Complexation of boric acid with environmentally important cations (i.e.,  $\text{Al}^{3+}$ ,  $\text{Fe}^{3+}$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ) is generally considered insignificant (Parks and Edwards 2005). Boric acid and borate ions may form complexes with organic matter (Power and Woods 1997; Chauveheid and Denis 2004; Parks and Edwards 2005), and have been observed to sorb weakly to dissolved organic matter in wastewater and to clays (Banerji 1969; Gu and Lowe 1990; Keren and Communar 2009; Parks and Edwards 2005). Adsorption to suspended solids has been hypothesized to explain elevated boron concentration observed in sediment porewater of North Carolina lakes continuously receiving effluent containing coal combustion residues (Ruhl et al. 2009). However, limited sorption to sludge has been confirmed in a number of Canadian wastewater treatment systems (e.g., median removal rate of 2.2%) (Environment Canada 2013c). This indicates that while sorption to suspended solids in solution could occur, removal of boric acid from solution is generally low. Sorption to clays and the co-precipitation of boron via sorption onto ferric iron compounds in sediment has been observed (Butterwick et al. 1989; Hart et al. 2005; Kot 2009). However, based on a low sediment-water ( $K_{\text{sdw}}$ ) partition coefficient value ( $\log K_{\text{sdw}} = 0.29$ ) (Gerke 2011a) and a low tendency to form complexes with environmentally

common cations, boric acid will generally tend to remain in the water column. Therefore, sediments are not anticipated to be a significant sink in freshwater ecosystems. Additionally, boric acid in sediments may reflux into the water column in addition to potential resuspension through bioturbation, dredging, seasonal floods, or mixing by turnover events. For example, low boron concentrations in the sediment of a river in Italy where elevated boron concentrations were observed in the water column (i.e., 1.1 mg B/L) were hypothesized to be caused by the leaching of adsorbed boron on soil minerals (Bonanno 2011).

### 7.1.3 Soil

Boron exists in soils in four main forms: water soluble, adsorbed, organically bound, and fixed in the clay and mineral lattices (Gupta 1993). Boron that is bound and fixed in clay and minerals (e.g., tourmaline) is insoluble and non-bioavailable in the long-term. Adsorbed or organically bound boron is also insoluble but may be released via desorption and organic matter degradation (Gupta 1993) as boric acid. Measurements of boron in soil differ depending on whether total boron or hot-water-soluble boron is measured (Gupta 1993). The total boron content of a particular soil is not a reliable indicator of available boron (Sah and Brown 1997), and the most common method for extracting available boron (as boric acid) is by hot water or from a saturated soil to water extract (Gupta 1993). Generally, less than 5% of the total background concentration of boron in soils is in a form that is bioavailable to plants (Gupta 1993), and plants absorb boron as molecular boric acid (Gupta et al. 1985).

In soils, boric acid is highly mobile, consistent with its low soil-water partitioning coefficient ( $\log K_{sw} = -1.06$ – $-2.2$ ) (Buchter et al. 1989; Elrashidi and O'Connor 1982; Equilibrium Environmental Inc. 2012; Janik et al. 2010; Majidi et al. 2010; Sauve et al. 2000; Singh 1971), and is expected to follow the water flux (Kot 2009). Boric acid does not undergo oxidation-reduction or volatilization reactions in soils, and therefore its concentration in soil solution is mainly controlled by adsorption reactions (Goldberg 1997). The main factors affecting boric acid adsorption in soil and its bioavailability are soil moisture, soil solution pH, soil texture (coarse vs. fine), soil content (organic matter, clays, metal hydroxides), and temperature (Goldberg 1997). The adsorption of boron reaches a maximum at pH 9, coinciding with an increase of the concentration of borate anions, which have more affinity with clays than boric acid (Keren and Bingham 1985). Adsorption to metal hydroxides (e.g., aluminium and iron oxides), clay minerals and organic matter generally occurs via ligand exchange, as summarized by Goldberg (1997). Mg-borates precipitates have been observed in soil samples from sites with high boron concentrations (Paliewicz *et al* 2015). Therefore, the bioavailability of boric acid in soil generally decreases as the fraction of these soil components increases. While multiple studies show evidence of sorption of boron (presumably boric acid) to soil, Mertens et al. (2011) recently observed that boric acid concentration in soil solutions of soil amended with boric acid did not decrease by ageing (a period of five months), indicating that added boric acid is not quickly bound and is highly mobile. Because of its incorporation into silicate structures or biomass, boron naturally present in soil was

determined to be much less soluble and therefore much less bioavailable than boric acid added to soil by amendment (Mertens et al. 2011).

## 7.2 Environmental persistence

A metalloid ion like boric acid is considered infinitely persistent because it cannot degrade any further, though it can transform into different chemical species or partition among different phases within an environmental medium. In other words, boron will be present in the environment indefinitely, generally as boric acid or the borate anion. Biodegradation and photodegradation are not applicable to boric acid or other inorganic boron-containing substances.

## 7.3 Potential for bioaccumulation

The bioaccumulation of metalloids is of potential concern because of the possibility of reaching internal body concentrations that can cause harm to the organisms accumulating these substances in their tissues or to the predators that eat these organisms. Accumulation of metalloids depends on their uptake process, which depends on the forms of the metalloid that are bioavailable and its depuration process once in the organism. Boric acid is considered highly bioavailable in the environment because of its high water solubility and relatively inert behaviour (e.g., absence of redox reactions).

### 7.3.1 Water and sediment

Generally, boric acid is not considered bioaccumulative in most aquatic organisms, particularly in invertebrates and fish, although bioaccumulation has been observed in some aquatic plants and algae.

Bioconcentration factors (BCFs) ranging from 23–766 (geometric mean of 75) have been measured in filamentous algae from the lower San Joaquin River and some of its tributaries (Saiki et al. 1993). Studying remediation of boron-polluted waters with duckweed (*Lemna gibba*), Del-Campo Marín and Oron (2007) also reported moderately high BCF values of 1100–2400 at boron concentrations in water of 0.3–1 mg/L. Lower BCF values of 500 and < 300 were observed in duckweed exposed to higher boron concentrations (e.g., 1.0–2.5 mg/L and > 5 mg/L) (Del-Campo Marín and Oron 2007). However, the bioaccumulation of boric acid in algae may be species-specific, because similar results were not duplicated in studies conducted with another species of duckweed (*Spirodella polyrrhiza*) and with the algae *Chlorella pyrenoidosa* (Fernandez et al. 1984; Davis et al. 2002).

Bioaccumulation of boric acid in invertebrates and fish is low. In invertebrates, Saiki et al. (1993) observed bioaccumulation factor (BAF) values of 16 (range of 7–60) in chironomids, 14 (range of 8–60) in amphipods, and 10 (range of 6–38) in crayfish. Low or no bioaccumulation was also observed in pacific oysters by Thompson et al. (1976). Average boron concentrations in some streams and biota in Turkey varied from 8.6–

16.7 mg/L in water and 1.98–2.84 mg/kg in invertebrates, leading to BAF values (based on boron concentrations in water and the whole-body levels in organisms) of 0.085–0.15 (Arslan 2013). Low BAF values ranging from 0.176–8.7 were also observed for aquatic invertebrates in a stream in Turkey where organisms were exposed to high concentrations of boron in surface water (1.61–3.45 mg B/L) and sediment (15.7–32.3 mg B/kg) (Emiroglu et al. 2010). Boric acid does not bioaccumulate in fish, as indicated by BAF values of < 0.1 in Chinook Salmon (*Oncorhynchus tshawytscha*) (Hamilton and Wiedmeyer 1990) and BCF values of 0.3 in Fathead Minnows (*Pimephales promelas*) and Green Sunfish (*Lepomis cyanellus*) (Suloway et al. 1983). Slightly higher BAF values were observed for Lake Whitefish (*Coregonus clupeaformis*) (51.5), Northern Pike (*Esox Lucius*) (63), Lake Cisco (*Coregonus artedii*) (64), Lake Trout (*Salvelinus namaycush*) (75) and White Sucker (*Catostomus commersonii*) (198) (Tsui and McCart 1981). BAFs calculated for fish from streams where boron concentrations ranged from 8.6–16.7 mg/L varied from 0.57–0.92 based on boron concentrations in water and in the muscle, liver and gills of Marmara chub (*Squalius cii*) (Arslan 2013). Low bioaccumulation potential in fish was also observed by Emiroglu et al. (2010), with the BAF calculated for European chub (*Leuciscus cephalus*) using concentrations measured in muscle, liver, gills and head, ranging from 0.78–41. In addition, low BAF values are reported for mosquitofish (BAF of 4), Bluegill (*Lepomis macrochirus*) (BAF of 2) and Largemouth Bass (*Micropterus salmoides*) (BAF of 0.7) (Saiki et al. 1993).

The studies conducted by Saiki et al. (1993) and Emiroglu et al. (2010) clearly determine that boric acid does not biomagnify in the environment, because concentrations of boron measured in organisms decrease with increasing trophic levels.

### 7.3.2 Soil

In terms of bioavailability for plants, generally less than 5% of the total boron background in soils is in available form (hot water-soluble) (Gupta 1993). Bioavailable boron is absorbed by roots as undissociated boric acid (Hu and Brown 1997; Mengel and Kirkby 1982; Marschner 1995). Dicotyldeon plants (e.g., legumes) in general require 4–7 times more boron (20–70 mg/kg) than monocotyledons (graminae) (5–10 mg/kg) (Bergmann 1988, 1995; Marschner 1995). According to Kabata-Pendias (2011), the average boron concentrations are 0.7–4.3 mg/kg in grains, 5–7.4 mg/kg in grasses and 14–40 mg/kg in clover. Shacklette et al. (1978) showed that trees and shrubs (usually containing 50–500 mg/kg of boron) generally contain 2–10 times more boron than vegetables.

Boric acid may bioaccumulate in some terrestrial plants. Dos Santos et al. (2010) reported that boron concentrations in shoots of kenaf (*Hybiscus canabinnus*), mustard (*Brassica juncea*), turnip (*Raphanus sativus*) and amaranth (*Amaranthus crentus*) range from 63–93 mg/kg, whereas the concentrations of soluble and total boron in soil were 3.8 and 6.4 mg/kg, respectively. Therefore, for these species, bioaccumulation potential is low. At boron concentrations in irrigation water of 5 mg/L, mean levels of boron in shoots of wheat (*Triticum aestivum*), tomato (*Solanum lycopersicum*) and silver beet (*Beta vulgaris*) were greater, ranging from 701–1110 mg/kg (Ayars et al. 1990, 1993).

Therefore, for some plants, boric acid bioaccumulation can be high, which is in line with the fact that boron is an essential nutrient for plants (see Section 8.1).

## **8. Potential to Cause Ecological Harm**

### **8.1 Essentiality**

Boron absorbed primarily as boric acid is an essential micronutrient for plant growth, development, and seed quality (Brown et al. 1999; Dordas et al. 2007; Hu and Brown 1997; Marschner 1995; Pilbeam and Kirkby 1983). There are indications of the involvement of boron in cell wall structure (Hu and Brown 1994; Brown et al. 2002), cell membrane integrity (Marschner 1995; Schon and Blevins 1990), sugar metabolism (Marschner 1995), biological membrane bindings, conversion of glucose-1-phosphate sugars to starch, and metabolism of nucleic acids (Cakmak and Römheld 1997). Boron plays a role in nitrogen fixation (Bolaños et al. 1996; Bellaloui et al. 2009), phenolic metabolism (Marschner 1995; Bellaloui et al. 2012a, 2012b), ion uptake (Marschner 1995; Goldbach 1985), and plasma-membrane-bound H<sup>+</sup>-ATPase (Schon and Blevins 1990; Camacho-Cristóbal and González-Fontes 2007; Camacho-Cristóbal et al. 2008).

Boron is an essential micronutrient for the development and reproduction of the African Clawed Frog (*Xenopus laevis*) (Fort et al. 1998, 2002). Abnormal development of the gut, craniofacial region and eye, visceral edema, kinking of the tail musculature, and an increase in the proportion of necrotic eggs and less viable embryos were observed in frogs that were administered a low boron diet compared to frogs given a diet supplemented with boric acid (Fort et al. 1998, 2002). Tests conducted with low boron-concentration water and water supplemented with boric acid show that boron is essential for Zebrafish (*Danio rerio*) embryo development and stimulates the growth of embryonic Rainbow Trout (*Oncorhynchus mykiss*) via its ability to bind to cellular *cis*-diols such as ribose (Eckhert 1998; Rowe and Eckhert 1999). The essentiality thresholds for Rainbow Trout and Zebrafish were determined to be approximately 0.1 mg B/L and  $2 \times 10^{-3}$  mg B/L, respectively (Rowe et al. 1998).

### **8.2 Ecological effects assessment**

#### **8.2.1 Water**

Many empirical studies are available on the acute and chronic toxicity of boric acid to aquatic organisms such as micro-organisms (ciliates), algae, invertebrates, fish, plants and amphibians. Results of aquatic toxicity testing for boric acid are generally reported as boron equivalent (mg B/L). Details are available in Environment Canada (2014i). Chronic toxicity data are of greater relevance and weighted more heavily as a line of evidence than acute data in this assessment, because they are a more sensitive indicator of potential for harm from long-term exposures. Given the persistence of boric acid, long-term exposures are particularly pertinent. Chronic data are therefore used to derive a critical toxicity value (CTV), which is a quantitative expression of a low toxic effect (e.g., IC<sub>25</sub>) that relates to the most sensitive toxicity endpoint for receptor organisms in the medium of interest.

Acute toxicity studies were identified for 35 species, including two algae species, one aquatic plant species, 15 invertebrate species, 15 fish species and two amphibian species. Acute toxicity endpoints range from a three-day no observed effect concentration (NOEC) (teratogenesis at hatching) of 0.109 mg B/L for Largemouth Bass embryos at hatching to a 96-hour lethal concentration (LC<sub>50</sub>) of 979 mg B/L for mosquitofish and a 48-hour LC<sub>50</sub> of 1376 mg B/L for midges (Birge and Black 1977; Black et al. 1993; Maier and Knight 1991). Data from these studies are not included or discussed further in this assessment, because they are not used to derive a CTV.

Chronic toxicity studies were identified for 40 species, including five algae species, eight plant species, eight invertebrate species, seven fish species, seven amphibian species, two species of zooplankton, one species of cyanobacteria, one species of protozoan, and one species of bacteria. Chronic toxicity endpoint values ranged from a 32-day lowest observed effect concentration (LOEC) (survival and teratogenesis) of 0.1 mg B/L for Rainbow Trout (embryo larval stages) in lab-reconstituted water to a 32-day LC<sub>50</sub> of 138 mg B/L for Rainbow Trout as well (Black et al. 1993; Birge and Black 1977). A full data set is available in Environment Canada (2014i). A lower chronic 28-day NOEC (survival and teratogenesis) of 0.001 mg B/L for embryo-larval stages of Rainbow Trout is generally considered unreliable (EU 2007a). Indeed, this result is several orders of magnitude lower than other toxicity studies, and the effects observed on Rainbow Trout may have resulted from boron deficiency (i.e., a level lower than the essentiality threshold of 0.1 mg B/L proposed by Rowe et al. 1998).

The importance of water quality characteristics and toxicity-modifying factors on boric acid aquatic toxicity is not well understood, and generally appears less significant than for other metalloids or metals (e.g., copper) (Black et al. 1993; Dethloff et al. 2009). Toxicity tests on Rainbow Trout performed with natural waters indicate higher toxicity threshold concentrations (up to 180 times greater) than those observed with reconstituted water (Black et al. 1993), indicating that the composition of the natural waters lessens boron toxicity to fish and possibly other aquatic organisms. The toxicity of boron to aquatic organisms in laboratory settings (added as boric acid) is generally not significantly modified by water hardness (Birge and Black 1977; Dethloff et al. 2009; Hamilton and Buhl 1990; Maier and Knight 1991; Soucek et al. 2011). However, a protective effect has been observed in certain acute toxicity tests conducted with invertebrate water flea species such as *Daphnia magna* and *Hyalella azteca* (MELP 1996) or *Ceriodaphnia dubia*, all with very hard waters (> 500 mg/L as calcium carbonate [CaCO<sub>3</sub>]) (Dethloff et al. 2009). Similarly, increasing sodium, chloride or sulfate concentrations do not significantly affect the toxicity of boron to aquatic organisms (added as boric acid) (Dethloff et al. 2009; Maier and Knight 1981), although protective effects of chloride have been observed with *Hyalella azteca* (Soucek et al. 2011). Complexation of boric acid and borates with organic compounds (e.g.,  $\alpha$ -hydroxy carboxylic acids) and adsorption to PM have been hypothesized as potential modifying factors for boron toxicity to aquatic organisms (Black et al. 1993). Dissolved organic carbon (DOC) has been shown to decrease the acute toxicity of boron to *Ceriodaphnia dubia* above 2 mg/L of DOC (Dethloff et al. 2009).

In 2009, the Canadian Council of Ministers of the Environment (CCME) published acute and chronic Canadian Water Quality Guidelines (WQGs) for Boron for the Protection of Aquatic Life (CCME 2009) based on the CCME protocol (CCME 2007). The long-term (chronic) WQG was developed using a statistical approach, because the minimum data requirements for a species sensitivity distribution (SSD) were met. A total of 28 data points (NOEC, effective concentration [EC<sub>10</sub>], maximum acceptable toxicant concentration [MATC] and LOEC data) for fish, invertebrates, plants and algae, and amphibians, generated using boric acid or boric acid–equivalent compounds, were used to derive the WQGs. The data set used in the chronic WQG is presented in Table B-1 (Appendix B). Long-term exposure guidelines are intended to protect all forms of aquatic life for indefinite exposure periods (≥ 7-day exposures for fish and invertebrates, ≥ 24-hour exposures for aquatic plants and algae) (CCME 2009). Therefore, the long-term WQG for boron of 1.5 mg B/L (i.e., a hazardous concentration to 5% of species [HC<sub>5</sub>], corresponding to the 5<sup>th</sup> percentile of the SSD) for freshwater was selected as the predicted no effect concentration (PNEC) to characterize risk to aquatic organisms in this assessment. This PNEC value is comparable or more protective than recent HC<sub>5</sub> values of 1.7 and 3.8 calculated with SSDs using chronic aquatic toxicity data (Borax Europe 2012; EU 2007a). Assessment factors (AFs) were applied to these latter values in the PNEC derivation process.

Recent aquatic toxicity studies, or studies that were unavailable for the 2009 WQG derivation, were systematically reviewed to confirm the protective nature of the water quality objective. Additional chronic boric acid toxicity results for one amphibian, three invertebrates, one fish and one algal species were all above the chronic PNEC value of 1.5 mg B/L (6.6–34.6 mg B/L), confirming that the PNEC adequately protects a wide variety of freshwater organisms (Fort 2011; Hall et al. 2014; Hansveit et al. 2001; Soucek et al. 2011; US EPA 2010).

### 8.2.2 Sediment

Sediment toxicity data are limited for boric acid. Data for benthic organisms were identified for freshwater midges (*Chironomus riparius*), the aquatic Blackworm (*Lumbriculus variegatus*) and the Fatmucket mussel (*Lampsilis siliquoidea*) (Gerke et al. 2011a, 2011b; Hall et al. 2014; Hooffman et al. 2000a). Toxicity values based on whole-sediment concentrations ranged from a 28-day NOEC value of 37.8 mg B/kg for the freshwater midge to a 21-day LC<sub>25</sub> (survival) of 363.1 mg B/kg for the Fatmucket mussel (Gerke et al. 2011a; Hall et al. 2014). Toxicity values based on porewater concentrations ranged from a 21-day NOEC (growth) of 10 mg B/L for the Fatmucket mussel to a 28-day LOEC (emergence) value of 59 mg B/L for the freshwater midge (Hooffman et al. 2000a; Hall et al. 2014) (see Appendix B-2).

Due to its high water solubility, boric acid is rapidly depleted from spiked sediments (Borax Europe 2012; Gerke et al. 2011a; Hall et al. 2014). In the test study conducted by Gerke et al (2011a), the test chambers were prepared two days prior to study initiation when midges were added, for a total duration of 30 days. On the 30<sup>th</sup> day of the study, the boron load in overlying water had increased to 75% of the total load from

31% on day 2, for a concentration in overlying water of 20.9 mg B/L. This concentration is almost identical to a 28-day NOEC of 20.4 mg B/L obtained by Gerke et al. (2011b) in a second study using spiked water only, and comparable to a 28-day NOEC value of 32 mg B/L measured by Hooftman et al. (2000a) for the same species. Therefore, the chronic toxicity observed for the freshwater midge may be mostly explained by the boron concentrations measured in the water column (Borax Europe 2012), and not by exposure to boron in sediment. To generate accurate sediment toxicity data, the overlying water must also be spiked at concentrations matching those of the targeted porewater exposures, as carried out by Hall et al. (2014) for the aquatic worm (*L. variegatus*). The worm growth endpoint showed much variability (possibly due to the fragmentation mode of worm reproduction) and is considered less reliable than the survival endpoint (Hall et al. 2014). Results for the Fatmucket mussel indicate that the primary route of boric acid exposure was through the aqueous phase, not the solid phase (Hall et al. 2014).

Due to the low partitioning of aqueous boric acid to sediment (see section 7.1.2) and the limited sediment toxicity studies available for boric acid, exposure via this media is given a low weight as a line of evidence. Therefore, a PNEC value is not calculated for benthic organisms.

### 8.2.3 Soil

Many empirical studies are available on the acute and chronic toxicity of boric acid to terrestrial organisms such as plants, invertebrates and soil micro-organisms. Acute and chronic soil toxicity data are available for 15 invertebrate species spanning nine different families; 26 plant species, including monocotyledons, dicotyledons and herbaceous plants and trees; and soil micro-organisms addressing two key soil biochemical processes (carbon transformation and nitrification). No studies aiming to establish the efficacy of boric acid as a pesticide (e.g., to control ants or termites) are included in this dataset (available in Environment Canada 2014j). Exposure to boric acid in soil is expected to be long term because of its persistence, and, therefore, chronic data are of greater relevance than acute data in this assessment because they are a more sensitive indicator of potential for harm from long-term exposures. All concentrations reported in soil toxicity studies and reports were converted into concentrations of boron equivalence to simplify comparison with exposure concentrations used in characterizing risk. The data were then used to derive a CTV. Robust Study Summaries (RSSs) were completed for all studies from which the toxicity data were used to derive the CTV (these RSSs are available upon request).

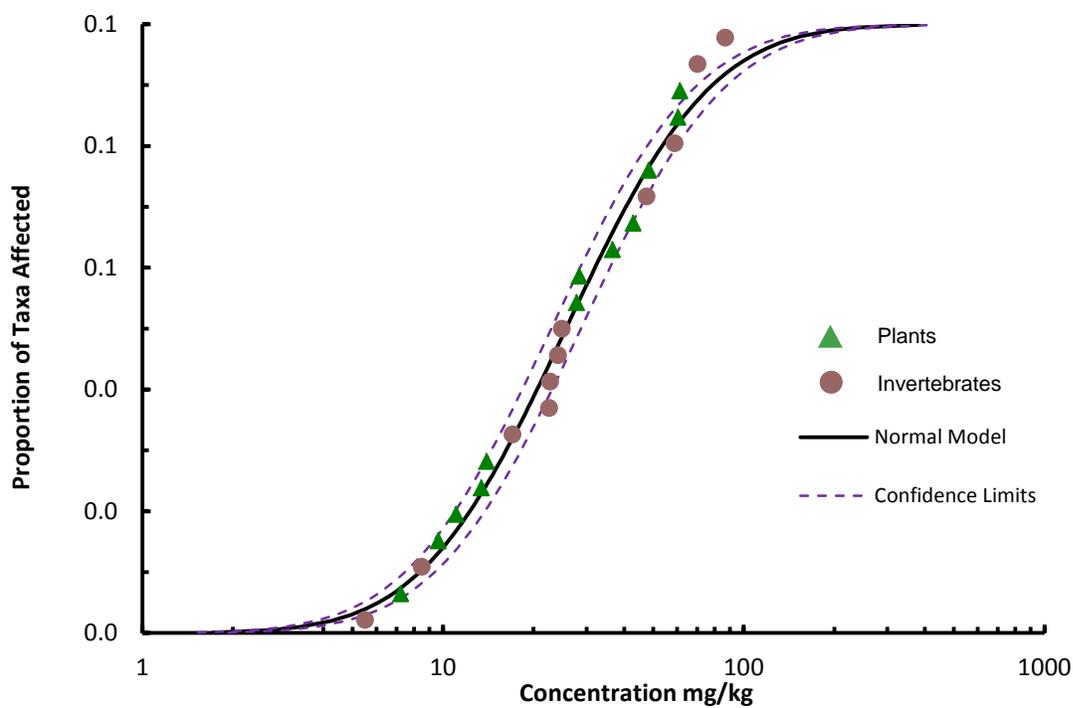
Reliable chronic data were identified for 25 species, including 13 invertebrate species and 12 plant species. The species were exposed to varying concentrations of boric acid in different types of North American, European and artificial soils. Individual chronic toxicity values for invertebrates (4–63 days NOEC/NOAEC [NOAEC = no observed adverse effect concentration], LOEC/LOAEC [LOAEC = lowest observed adverse effect concentration] and EC/IC<sub>10-50</sub> [IC = inhibitory concentration]) ranged from 1.43–630 mg B/kg (Amorim et al. 2012; Becker et al. 2011; Becker-Van Slooten et al. 2003;

Environment Canada 2014k; ESG International Inc. and Aquatera Environmental Consulting Ltd. 2003; Huguier et al. 2013; Moser and Becker 2009a, 2009b, 2009c, 2009d, 2009e; Moser and Scheffczyk 2009; Owojori et al. 2011; Princz and Scroggins 2003; Princz et al. 2010; Smit et al. 2012; Stantec Consulting Ltd. and Aquaterra Environmental Consulting 2004). Individual chronic toxicity values for plants (14–90 days NOEC, LOEC and EC/IC<sub>10-50</sub>) ranged from 1.75–242 mg B/kg (Anaka et al. 2008; Bagheri et al. 1994; Becker et al. 2011; Environment Canada 2014k; Forster and Becker 2009; Gestring and Soltanpour 1987; Hosseini et al. 2007; Miller 2013). Toxicity symptoms in plants include yellowing, spotting or drying of leaf tissues (Gupta 1985). Further detail is available in Environment Canada (2014j).

The toxicity of boric acid to soil organisms depends on its bioavailability in the dissolved fraction of soil solution. Soil moisture has been determined to be the most important soil property (among soil moisture content, background boron, clay content and cation exchange capacity) for explaining boron bioavailability and toxicity to plants (Mertens et al. 2011). Adsorption reactions (see Section 7.1.3) are dependent on soil moisture and also pH, soil texture and soil content. Differences in soil toxicity values of approximately a factor of two for *E. albidus* and *F. candida* in LUFA Speyer and Organisation for Economic Co-operation and Development (OECD) standard soils were explained by a reduction in boron bioavailability, presumably because of adsorption given that OECD soil has greater organic matter and clay content than LUFA soil (Amorim et al. 2012). However, the impacts of soil ageing (up to five months) and sorption on the bioavailability of boric acid to plants in soil amended with boric acid were recently found to be minimal, indicating that added boric acid was not quickly bound (Mertens et al. 2011). This suggests that the effects of toxicity-modifying factors on the toxicity of boric acid in soil are generally low (less than one order of magnitude) or slow-occurring, and consequently they are not further considered in this assessment to characterize effects. Additionally, because the fraction of bioavailable boron in natural background concentration is low (see Section 7.1.3), the possible contribution of natural background concentration to the toxic effects of boric acid in soil organisms is considered negligible compared to boric acid concentrations added to soil as a result of anthropogenic activities, which are much more bioavailable. Based on these considerations, the added risk approach, which assumes that only the anthropogenic added fraction of boron (as boric acid) in soil may contribute to risk, was used to characterize the effects of boric acid on soil organisms (ICMM 2007a). Therefore, the PNEC derived for soil organisms focuses on the added fraction of boric acid in soil only and is referred to as a PNEC<sub>added</sub>.

The large data set available for boric acid meets the minimum criteria of species of the CCME (2006) and Metals Environmental Risk Assessment Guidance (MERAG) (ICMM 2007b), allowing derivation of a CTV using an SSD. The data used to develop the SSD are presented in Table C-1 (Appendix C) and include a total of 23 species (11 invertebrate and 12 plant species). The preferred endpoints to be used in the SSD were chosen following guidance from the CCME for the derivation of WQGs (CCME 2007) and include, in decreasing order of preference, EC<sub>10</sub>, EC/IC<sub>20</sub>, IC<sub>25</sub> and NOECs. When more than one value for an endpoint was available for a single species (including data for different soils), the geometric mean of the toxicity values was calculated and used in

the SSD. When a single value was available for a number of endpoints (e.g., biomass, growth) within one study, the lowest endpoint toxicity value for a given species was selected.



**Figure 8-1: Species sensitivity distribution (SSD) for boron based on chronic toxicity data for soil organisms. The Normal Model fit to data is shown on the graph along with the 95% confidence intervals.**

The software SSD Master v3.0 (SSD Master 2010) was used to plot the SSD (Figure 8-1). Several cumulative distribution functions (CDFs) (Normal, Logistic, Gompertz and Fisher-Tippett) were fit to the data using regression methods. Model fit was assessed using statistical and graphical techniques. The best model was selected based on consideration of goodness-of-fit and model feasibility. Model assumptions were verified graphically and with statistical tests. The Normal Model provided the best fit of the models tested upon visual inspection, the lowest levels of statistical variability (residuals), even distribution of the residuals, and lowest confidence interval spread. The Extreme Value Model had a slightly better Anderson-Darling Statistic test value ( $A^2 = 0.254$  ( $p < 0.05$ )) compared to a ( $A^2 = 0.259$  ( $p < 0.05$ )) for the Normal Model. However, the confidence interval spread of the Extreme Value was greater (i.e., 2.78–5.06) and the Normal Model was preferred. The  $HC_5$  of the SSD plot is 6.08 mg B/kg with lower and upper confidence limits of 5.42 and 6.82 mg B/kg, respectively.

The  $HC_5$  of 6.08 mg B/kg calculated from the SSD is selected as the CTV for soil organisms. This value is based on a chronic SSD that covers multiple species and taxa, and therefore no assessment factor is used to derive the added PNEC for soil organisms. Hence, the  $PNEC_{added}$  for soil organisms is 6.08 mg B/kg.

## 8.3 Ecological exposure assessment

Environmental concentrations of boric acid are reported as concentrations of boron in a particular medium.

### 8.3.1 Ambient/background concentrations in Canada

#### 8.3.1.1 Surface waters

Concentrations, where available, of recent total and dissolved boron measured in water bodies across Canada (Table 8-1) indicate that while some of the high concentrations may be related to the contribution from point-source anthropogenic releases, concentrations up to the 50<sup>th</sup> percentile should be representative of the regional biogeochemical background concentration (ICMM 2007c). These data were collected between 2009 and 2012 as part of Environment Canada's Monitoring and Surveillance Program under the CMP (Environment Canada 2013c).

**Table 8-2: Concentrations of boron in surface waters of minimally impacted areas of Canada (2009–2012)**

Location	Concentration range (µg/L)	Median (µg B /L)	Reference
Pacific and Yukon Region <sup>A</sup>	ND–100	5.75 (dissolved = 3.43)	Environment Canada 2013c
Prairie and Northern Region <sup>B</sup>	2.8–43.6 (dissolved = 2.9–78.6)	14.33 (dissolved = 13.61)	Environment Canada 2013c
Ontario Region (Hudson's Bay) <sup>C</sup>	1.2–806 (dissolved = 1.2–729)	30.86 (dissolved = 29.48)	Environment Canada 2013c
Ontario Region (Erie-Superior-Ontario) <sup>D</sup>	0.1–65.7	8.70	Environment Canada 2013c
Quebec Region <sup>E</sup>	0.8–23.4	6.25	Environment Canada 2013c
Atlantic Region <sup>F</sup>	0.3–347	3.59	Environment Canada 2013c

ND: non-detected

<sup>A</sup> Sample size: total concentration (n=3468) and dissolved (n=715).

<sup>B</sup> Sample size: total concentration (n=175) and dissolved (n=175); total boron concentrations should be greater than dissolved boron, because they represent the dissolved and particulate fractions; the dissolved boron upper-range value of 78.6 µg/L greater than the total boron concentration of 43.6 µg/L may be due to analytical or data entry errors.

<sup>C</sup> Sample size: total concentration (n=808) and dissolved (n=786).

<sup>D</sup> Sample size: total concentration (n=108).

<sup>E</sup> Sample size: total concentration (n=228).

<sup>F</sup> Sample size: total concentration (n=969).

### 8.3.1.2 Soils

Concentrations of total boron or extractable boron in soils of Canadian provinces are dependent on soil types, soil origin and pH (Parks and Edwards 2005). Higher concentrations of boron may be found in clay, loam or soils rich in organic matter than in sandy soil (Gupta 1967). The highest background concentrations are found in sedimentary rocks, particularly those originating from clay-rich marine sediments (Butterwick et al. 1989). Boron retention in soil depends on boron concentration in the soil solution, soil pH, texture, organic matter, cation exchange capacity, type of clay and mineral coating on the clay (see Section 7.1.3). Less than 5% of the total boron in soils is bioavailable to plants (Gupta 1993).

The U.S. Geological Survey (USGS 1984) reported an average boron concentration of 33 mg/kg (range < 20–300 mg/kg) in surface soils from the conterminous United States, with concentrations slightly higher in the eastern U.S. Boron concentrations in soil are also high in California. In Canada, there is less data available on the concentration of total boron in soil, but median total boron concentrations reported for a limited number of sites sampled throughout Canada (20) between 1962–1973 range from 10.7–30 mg B/kg (Agriculture and Agri-Food Canada 2013). It is unknown whether agricultural activities occurred at these sites prior to sampling. In British Columbia, total boron concentrations in soil range from 1–90 mg/kg, with median concentrations from 1–26 mg/kg; concentrations are high in the Peace River area, and are considered deficient in the rest of B.C. (BC MOE 2005). In New Brunswick, the baseline boron soil concentration, characterized as 97th percentile boron soil concentration, is reported as 8 mg/kg (Government of New Brunswick 2005). In Alberta, extractable boron (hot water) measured in soil from 42 benchmark sites across the province ranged from 0.29–2.32 mg/kg with a mean of 0.92 mg/kg (Penny 2004). In the Flin Flon soil study, extractable boron ranged from 0.1–19 mg/kg from residential surface soils around east and west Flin Flon and Channing, Manitoba, and Creighton, Saskatchewan (Intrinsik 2010).

### 8.3.2 Exposure scenarios and predicted environmental concentrations

Exposure scenarios were developed for various activities that represent significant sources of release of boric acid and its precursors to the environment. These scenarios are presented in this section by sectors of activity. For each scenario, predicted environmental concentrations (PECs) expressed as elemental boron are estimated in order to assess exposure to boric acid for ecological receptors. Depending on the environmental media to which releases of boric acid are expected to occur, PECs are estimated for surface water or soil. PECs were not developed for air, because boric acid released to this medium is expected to be removed from this compartment by wet and dry deposition and to be ultimately deposited on soil or in water bodies. PECs were also not developed for sediment, because boric acid released to freshwater environments tends to remain in the water column due to its high water solubility.

PECs for the aquatic environment were primarily estimated using adequate data on measured concentrations of boron in relevant environmental media when available, as

they provide evidence for exposure to organisms in Canada from specific sectors of activity (Sections 8.3.2.1–8.3.2.9). Although based on measured concentrations, these concentrations are labelled as “predicted” because measurements taken from specific sites for a sector of activity are used to represent the sector as a whole. The adequacy of measured environmental concentrations was assessed considering factors such as distance between sampling sites and source of release, the year the samples were collected, analytical method used, and number of available measurements. When available, preference was given to dissolved boron concentrations instead of total boron concentrations, because they comprise the fraction of boron that is most bioavailable. When it was not specified whether concentrations were reported for total or dissolved boron, the concentrations were assumed to be dissolved in order to be conservative (i.e., assuming high bioavailability). This assumption has minimal consequence to the final results, because dissolved and total boron measurements are generally almost identical, thus confirming the high bioavailability of boric acid in surface water. PECs consist of ranges of concentrations for individual sites, or ranges of arithmetic means or medians for multiple sites. When data were available, these PECs were compared to concentrations from designated “reference” or “unexposed” sites to confirm that the measured concentrations observed at the exposed sites were the results of anthropogenic releases.

When measured concentrations of boron in the aquatic environment were deemed inadequate or not available PECs were estimated. These PECs were determined based on a tiered approach, i.e., using conservative assumptions for the first calculations and then refining these assumptions where a potential concern is identified, to increase the realism of the scenario. For many industrial sectors, the main medium of potential environmental concern is surface water, because boric acid is expected to be released from industrial facilities directly to surface water (direct discharges) or indirectly through off-site wastewater treatment systems (indirect discharges). For each of these sectors, estimated aquatic concentrations (EACs) are the environmental concentrations resulting from the releases of these facilities or activities (e.g., down-the-drain-releases) and were calculated as a range across the related releases and exposure conditions. When data were modelled for direct discharges, a range of PECs for a particular sector was obtained by adding the median (50<sup>th</sup> percentile) background concentration of boron in water to the range of the related EACs (i.e., PEC range = EAC range + median background concentration). When data were estimated for indirect discharges, a range of PECs for a particular sector was obtained by adding, to the range of the related EAC, both the median background concentration of boron in water and the range of boron concentrations resulting from “down-the-drain” releases (i.e., releases from consumer use; see Section 8.3.2.9). As a conservative approach, the highest median background concentration (0.031 mg/L [Table 8-1]) was used.

For the soil compartment, measured concentrations in the vicinity of a site were compared to concentrations from designated “reference” or “unexposed” sites representing regional background conditions, when data were available (Section 8.3.2.3). When designated background concentrations were unavailable, environmental concentrations representing only the anthropogenic addition of boron in soil as a result

of a specific activity were estimated. These concentrations are referred to as  $PEC_{added}$ , because they ignore the potential contribution of bioavailable boric acid from naturally occurring boron soil background concentration. However, the availability of non-anthropogenic metals in soil is generally low, and because the bioavailable fraction of boron in soil is known to be low (< 5% [Gupta 1993]), assuming a default bioavailability in soil equal to zero is considered reasonable (Struijs et al. 1997). Conservative assumptions were nevertheless used to generate soil  $PEC_{added}$  values, including the use of a high soil-water partitioning coefficient value (i.e.,  $\log K_{sw} = 2.2$ ) as well as assuming no loss via run-off, leaching or uptake by plants in modelling.  $PEC_{added}$  values were generated to estimate the addition of boric acid in soil expressed as boron, resulting from air emissions (sections 8.3.2.1, 8.3.2.5 and 8.3.2.12) or from biosolids application (Section 8.3.2.9). Further details are available in Environment Canada (2014b, 2014f, 2014h).

### **8.3.2.1 Exposure scenario for power generation using coal**

Boron is naturally present in coal, in concentrations ranging from 16–217 mg B/kg in Canadian coal, with the highest concentrations usually found in lignite and sub-bituminous coal used for power generation in Saskatchewan and Alberta (Goodarzi 2013). The combustion of boron-containing coal to generate electricity releases boron to the environment. Boron is emitted to air in particulate and gaseous forms, which can be expected to be deposited or washed out by rain and snow to terrestrial and aquatic ecosystems. Additionally, boron may be released to the aquatic environment by discharges from power plant wastewater effluents, fly ash and bottom ash containment areas (i.e., ash lagoons), coal piles, or groundwater seepage from containment areas. Additional information on boron releases associated with this sector can be found in Environment Canada (2014b).

An exposure scenario was developed for the Wabamun Lake area located within the North Saskatchewan River watershed, based on boron concentrations measured in various environmental media. This area is used as a realistic worst-case scenario to assess releases from coal-fired power plants in Canada. A number of water quality surveys were conducted by the Alberta Ministry of the Environment at Wabamun Lake in 2002 and 2005 (Alberta Environment 2002, 2003a, 2003b, 2006), and measured boron concentrations revealed relatively high amounts of boron (Table 8-3). Several coal mines are located in the Wabamun Lake area and in the vicinity of the power plants, and therefore measured concentrations in the lake water may include contributions from both coal-fired power generation and coal mining industrial activities. Soil samples were collected as part of an air deposition survey conducted in the Wabamun Lake area between 1994 and 1997 by the Geological Survey of Canada (GSC) (GSC 2002); no adequate designated soil background concentrations were identified for comparison. Generally, the low cumulative deposition rate of boron around Wabamun Lake (18.44 grams per hectare accumulated over four years), and the lack of apparent correlation between soil concentrations and boron measurements in moss used to monitor metal deposition, suggest that boron concentrations in soil in the region may be largely due to geogenic sources. In order to assess increases of boron in soil as

a result of air emissions, the added soil concentrations were estimated over a period of 50 years using the cumulative deposition rate calculated by the GSC (2002) and a model converting soil deposition to soil concentration (Environment Canada 2014I). Added boron concentrations in soil as a result of air emissions over a period of 50 years were estimated to be relatively low (Table 8-3).

**Table 8-3: Summary of concentrations of boron in the Wabamun Lake area, Alberta**

Medium and units	PEC range (mg/L)	PEC median (mg/L or mg/kg)	Sample size (n=)	Sampling period	Reference
Water	0.786–1.0	0.884	116	1996–2005	Alberta Environment 2002, 2003a, 2003b, 2006
Soil	-	0.322 <sup>A</sup>	-	2002	GSC 2002; Environment Canada 2014I

<sup>A</sup> The concentration of boron added to soil (PEC<sub>added</sub>) as a result of boron deposition rate from GSC (2002).

### 8.3.2.2 Metal mining

Mining activities can include both ore extraction via open-pit or underground mining, and ore processing at a milling facility (commonly referred to as a mill). Ore typically consists of small amounts of valuable minerals in close association with much larger amounts of waste minerals of no economic value (gangue). The valuable ore minerals are separated (liberated) from the gangue in milling operations to obtain higher quality metal. Major steps in ore processing at milling facilities include grinding and crushing, chemical/physical separation and dewatering (Environment Canada 2009b). While boron compounds are not mined in Canada, boron is ubiquitous in nature and may be found in ores at varying concentrations. For example, boron can be associated with “vein-type” gold mineralization (Boyle 1974; Closs and Sado 1981). Additionally, borates are used in precious metals recovery (Borax 2013), where they serve as fluxes during fire assaying of ore or final refining of precious metals (Paliewicz *et al* 2015). Smelting of precious metals concentrates may take place in a small furnace located within the milling facility of precious metals mining operations (Paliewicz *et al* 2015; U.S. EPA 1994). Less than four companies indicated purchasing between 10 000 – 100 000 kg of a boric acid precursor, and less than four companies indicated purchasing between 1000 and 10 000 kg of the same precursor for the year 2012, as a result of voluntary stakeholder engagement activities (Environment Canada 2013b). Because borates may be a major ingredient of fluxes in precious metal recovery (12-50 wt%) (Bugbee 1981), high concentrations of boron may be found in the slags generated by this activity (Paliewicz *et al* 2015). Laboratory leachability tests conducted on pulverized slags samples from three Canadian mining operations, show that a significant amount of boron (3-12 wt% of the initial mass of solid slag) may be released within 24-hr (Paliewicz *et al* 2015). Therefore, boric acid could be released into the environment as a result of the mining and production of metal concentrates.

Samples were collected by AMEC (2005) from a tailings area that received wastes from a former milling facility that processed an estimated 60 000 000 kg of boron-containing slag and refinery bricks (75% slag; 25% brick) for a precious metal refinery in addition to gold ore (Paliewicz *et al* 2015). Sampling results showed boron concentrations of up to 242 mg/L in local groundwater, and up to 9.1 mg/L in locally discharged surface water (AMEC 2005). As described in Paliewicz *et al* (2015), the AMEC (2005) study did not examine boron-concentrations in the river adjacent to the tailings area, but determined from the drainage pattern of the tailings area that the river flowing in the vicinity of the site was likely receiving discharges from the tailings area as surface runoff, groundwater seepage, or decanted dam water (AMEC 2005).

Reports from Environment and Climate Change Canada for 118 metal ore mining and milling sites that conduct environmental effects monitoring (EEM) under the *Metal Mining Effluent Regulations* (MMER) were reviewed (Environment Canada 2014m). Measurements of boron concentrations in effluent or in the receiving environment where effluent is discharged were available for 70 sites (approximately 60% of all sites) from 2004–2013, including four sites in the Quebec region, seven sites in the Atlantic region, 10 sites in the Pacific region, 22 sites in the Ontario region, and 27 sites in the Northern-Prairie region. Based on available data for monitoring of effluent and the exposure area, 54 sites showed low boron concentrations ( $\leq 0.2$  mg B/L), nine sites showed moderate boron concentrations ( $> 0.2$ – $0.5$  mg B/L), five sites showed high boron concentrations in the exposure area ( $> 0.5$ – $1.4$  mg B/L), and one site showed extremely high concentrations in the exposure area ( $> 10$  mg B/L) (Table 8-4) (Environment Canada 2014m). The concentrations reported in the effluent at one site ( $< 0.7$  mg B/L) could not be interpreted, because of a high detection limit.

Of the sites showing high boron concentrations in the exposure area, site 1 is an integrated base metal mine and smelter, site 2 is a uranium mine, site 3 is a uranium ore processing mill, site 4 comprises a number of base metals and precious metals mines discharging into a common waterbody, site 5 is a former metal ore processing mill, and site 6 is a mill that processes a range of ores and feeds. Further details are available in Environment Canada (2014c).

**Table 8-4: Summary of measured concentrations of boron in surface water near metal mines (Environment Canada 2014m)**

Site and type of facility	Reference or exposed area	PEC range (mg total B/L)	Sample size (n=)	Sampling period
65 mining sites	Exposed area	Negligible – $\leq 0.5$	-	2004–2013
Site 1 – mine and smelter	Exposed area <sup>A</sup>	1.02–1.17	5	2011
Site 1 – mine and smelter	Reference	$< 0.01$	5	2011
Site 2 – mine	Exposed area <sup>B</sup>	0.29–0.56	2	2004
Site 2 – mine	Reference	0.003–0.023	3	2004

Site and type of facility	Reference or exposed area	PEC range (mg total B/L)	Sample size (n=)	Sampling period
Site 3 – mill	Exposed area	0.22–1.3	5	2011
Site 3 – mill	Reference	< 0.010–0.010	8	2011
Site 4 – multiple mines	Exposed area	0.168–0.907	29	2003–2010
Site 4 – multiple mines	Reference	0.03–0.14	39	2003–2010
Site 5 – mill	Exposed area	0.047–0.687	6	2004–2007
Site 5 – mill	Reference	0.013–0.016	2	2004–2007
Site 6 – mill	Exposed area	14.6–20.1	14	2010–2013
Site 6 – mill	Reference	< 0.01	14	2010–2013

<sup>A</sup> Total boron concentrations; water samples consisted of partially diluted effluent (i.e., concentration of 75% effluent) at the time of sampling (Environment Canada 2014m).

<sup>B</sup> Data only for the lake receiving effluent. Average boron yearly measurements from 1995–1998 ranged from 0.3–0.34 mg B/L.

### 8.3.2.3 Base metals and precious metals smelting and refining

A number of Canadian facilities involved in the smelting or refining of base and precious metals reported using boric acid precursors in their processes. Less than four companies whose primary sector of activity is base metal smelting reported importing between 50 000 and 100 000 kg of a boric acid precursor in 2008 (Environment Canada 2009a). Less than four companies indicated purchasing between 100 000 and 1 000 000 kg of a boric acid precursor, and less than four companies indicated purchasing between 1000 and 10 000 kg of another boric acid precursor for the year 2012, as a result of voluntary stakeholder engagement activities (Environment Canada 2013b). In base metal smelting and gold metallurgy, borates are used as flux, dissolving metallic oxide impurities that may be subsequently removed with slags, and also as a cover flux to protect metals against oxidation (Borax 2013; Cole and Ferron 2002). Slags generated at certain processing steps from some base metals smelting facilities such as lead smelters, may contain up to 25 wt% of boron oxide (Jaeck 1989). Based on Paliewicz *et al* (2015), it is inferred that the leachability of boron (as boric acid) from these slags could be significant. Boron may also be present in the various ores and concentrate being processed. Releases of boron to the environment from base and precious metals smelting and refining facilities may occur via air emissions (Environment Canada 2013a) or effluent releases to the aquatic environment as a result of processing activities.

Results from studies conducted near a smelter in British Columbia and two smelters in Manitoba indicate that air emissions may not contribute significantly to boron levels in soils or in water bodies located near smelters (exposed areas), because those levels are generally comparable to levels from reference (unexposed) areas (CEI 2003; Intrinsic Environmental Sciences Inc. *et al.* 2011; Jacques Whitford 2008; Jones and Henderson 2006; Jones and Phillips 2003; Stantec 2009). Further details are available in Environment Canada (2014d).

Elevated boron concentrations are reported in the effluent of a number of smelters, including three combined mining and smelting sites that conduct EEM (Ouellet et al. 2013; Environment Canada 2014m). However, boron concentrations in receiving aquatic environments in exposed areas downstream of smelter effluent discharges are generally comparable to boron concentrations measured in reference sites (Table 8-5). The samples from Site 1 (also discussed in the metal mining sector exposure characterization in subsection 8.3.2.2), where elevated dissolved boron concentration was measured (1.17 mg B/L), consist of partially diluted effluent (75% effluent) (Environment Canada 2014m). Further details are available in Environment Canada (2014d).

**Table 8-5: Summary of measured concentrations of boron in surface waters in the vicinity of smelters and refineries**

Site	Reference or exposed area	PEC range (mg B/L)	Sample size (n=)	Sampling period	Reference
Site 1	Exposed	1.02–1.17	5	2011	Environment Canada 2014m
Site 1	Reference	< 0.01	5	2011	Environment Canada 2014m
Site 2	Exposed	0.03–0.07	3	2011	Environment Canada 2014m
Site 2	Reference	0.002–0.006	5	2011	Environment Canada 2014m
Site 3	Exposed <sup>A</sup>	0.016–0.054	13	2011	Environment Canada 2014m
Site 3	Reference <sup>A</sup>	0.032–0.044	2	2011	Environment Canada 2014m
Site 4	Exposed <sup>A</sup> (far-field)	Negligible – $2.7 \times 10^{-3}$	58	1996–1997	Ryan 2005
Site 4	Reference <sup>A</sup>	Negligible – $2.4 \times 10^{-3}$	58	1996–1997	Ryan 2005

<sup>A</sup> Dissolved boron concentrations.

### 8.3.2.4 Coal mining

The mining of coal reserves may lead to the release of boron naturally present in coal (16–217 mg B/kg) into the environment (Goodarzi 2013). Releases to the aquatic environment may occur as a result of discharges and seepage from tailing ponds, mining dewatering activities, surface water run-off from disturbed areas, and leaching from exposed coal-bearing materials or waste rock piles (BC MOE 1978; Craw et al.

2006; NRC 1981; Seierstad et al. 1983). Further details are available in Environment Canada (2014e).

Most coal mines in Canada are located in Alberta (nine in total) and British Columbia (10). A total of two areas in these provinces were selected for exposure scenarios based on their number of mines and the availability of studies reporting environmental concentrations of boron: the Elk River watershed in British Columbia, and the McLeod and Smoky River watersheds in western Alberta. Results from the studies show that, in some cases, boron concentrations were slightly elevated downstream of mine activities compared to select reference areas (Casey 2005; Frenette 2007) (see Table 8-6).

**Table 8-6: Summary of measured concentrations of boron near coal mines**

Medium and units	PEC range	Number of samples (n=)	Sampling period	Reference
Water (mg B/L), exposed area	0.004–0.061	92	1998–2007	Casey 2005; Frenette 2007
Water (mg B/L), reference area	0–0.017	64	1998–2007	Casey 2005; Frenette 2007

### 8.3.2.5 Oil sands extraction and processing

Boron occurs naturally in the bitumen found in Athabasca oil sands deposits in northern Alberta and in formation waters and reservoir rock that may be disturbed during extraction/mining of the deposits (Hitchon et al. 1977; Williams et al. 2001; Frank et al. 2014). Elevated boron concentrations (0.128–3.7 mg B/L) have been reported in oil sands process waters (OSPW) from surface mining operations, which are stored in tailing ponds (Frank et al. 2014; Gupta 2009; Holden et al. 2013; Redfield et al. 2004; Renault et al. 1998; Puttaswamy et al. 2010; Renault et al. 2001; Van Den Heuvel et al. 1999) and higher concentrations have been reported in OSPW from underground (in-situ) operations (76.6–196 mg B/L) (Williams et al. 2001). Bitumen extraction and processing generates large amounts of coke, and elevated boron concentrations have been measured in coke leachate (495–749 mg B/L) (Puttaswamy et al. 2010). Releases of boron to the aquatic environment may occur as a result of surface water run-off from mining areas and seepage from tailing ponds and OSPW storage ponds (Frank et al. 2014; Pollet and Bendell Young 2000).

Atmospheric deposition via wet and dry process has also been identified as a source of boron to soil in the Athabasca oil sands region (Bari et al. 2014). Boron concentrations in samples collected using four bulk samplers over a three-month period in winter 2012 were greater near oil sands extraction and processing sites, with a maximum average daily deposition rate of 3.6 µg/m<sup>2</sup>/d within a 20-km radius, compared to deposition rates of 0.4 and 0.3 µg/m<sup>2</sup>/d at distant monitoring stations (48 and 68 km away, respectively) (Bari et al. 2014). Over a 50-year period, such a deposition rate would lead to an added boron concentration in soil of 0.92 mg B/kg (Table 8-7) (Environment Canada 2014f). Further details are available in Environment Canada (2014f).

Concentrations of total and dissolved boron available for multiple monitoring stations situated on the Athabasca River and many of its tributaries from the Regional Aquatics Monitoring Program (RAMP) and the Joint Canada-Alberta Oil Sands Environmental Monitoring program are generally low (Table 8-7) (JOSM 2014; RAMP 2014). RAMP designates its monitoring stations as “baseline” stations situated upstream of focal projects at the time of sampling, or as “test” stations located downstream of focal projects at the time of sampling (RAMP 2013). Baseline stations may reasonably be considered representative of “unexposed” conditions and test stations representative of “exposed” conditions; however, because oil sands development has been occurring for many decades in a large area, it can be difficult to clearly identify background (or reference) stations within the Athabasca River watershed. A dissolved boron concentration above 1 mg B/L (i.e., 1.7 mg B/L) was detected in only one instance, at a test station (MAR-2A) located on the MacKay River in winter 2010 (RAMP 2014). The second-highest dissolved boron concentration measured at this site is 0.193 mg B/L (also measured in the winter), with a median concentration (from 2009–2012) of 0.059 mg B/L (n=14). Although the cause of the elevated boron concentration measured at station MAR-2A is unknown, based on the large dataset available this measurement seems to be an isolated event.

**Table 8-7: Summary of measured concentrations of boron in the Athabasca River watershed**

Medium and units	PEC range and 95 <sup>th</sup> percentile	Number of samples (n=)	Sampling period	Reference
Water (mg B/L), unexposed station <sup>A</sup>	0.004–0.892 (0.167)	392	1997–2012	RAMP 2014
Water (mg B/L), exposed station <sup>A</sup>	0.004–1.72 (0.164)	589	1997–2012	RAMP 2014
Water (mg B/L) <sup>B</sup>	0.0001–0.172	332	2003–2011	JOSM 2014
Soil (mg B/kg) <sup>C</sup>	0.92	-	2012	Bari et al. 2014; Environment Canada 2014

<sup>A</sup> Dissolved boron concentrations are presented for a total of 43 water bodies “unexposed” and “exposed” stations based on “baseline” and “test” classification in RAMP (2013). 95<sup>th</sup> percentile concentrations were calculated for each category using aggregated data for all samples.

<sup>B</sup> Difficult to determine whether monitoring stations are for exposed or unexposed areas.

<sup>C</sup> Added boron concentration to background levels in soil as a result of bulk deposition rates over a period of 50 years (based on Bari et al. 2014).

### 8.3.2.6 Oil and gas extraction

A number of boric acid precursors are used in oil and gas extraction activities, including drilling and hydraulic fracturing. The quantities of a number of boric acid precursors imported into Canada by oilfield service companies (involved in drilling and hydraulic fracturing activities) ranged between approximately 1 000 000–10 000 000 and 10 000 000–50 000 000 kg yearly between 2009 and 2012 (CBSA 2013). They

generally serve as crosslinkers to maintain fluid viscosity as temperature increases down the well (FracFocus 2014; US EPA 2012a). Releases of boric acid to the environment may occur as a result of the transportation and on-site storage of boric acid precursors, the preparation of drilling muds and hydraulic fracturing fluids, and the storage, treatment and disposal of flowback fluid and produced water (CCA 2014). Flowback fluid consists of the chemical additives that were mixed into the fracturing fluid and the formation water that may be high in dissolved solids (CCA 2014). Produced water is water trapped in underground formations that is brought to the surface with the oil and gas (CSUR 2014). Boron has been measured in flowback fluid and produced water in Canada (0.05–30.6 mg B/L), due primarily to natural sources found in the oil and gas formations (Cheung et al. 2009; MDDEP 2010a).

Provinces and territories are the primary regulators of oil and gas exploration and extraction, including chemical use, water use, water storage and disposal of wastewater (including flowback fluids and produced water). Flowback fluids and produced water are recovered and stored in lined surface ponds or storage tanks, and are either treated for re-use or disposed of. Wastewater disposal occurs either on-site or off-site through injection into a deep wastewater disposal well or at a waste treatment facility (CCA 2014). The wastewater management option that is authorized depends on the geological characteristics of the site where the activity occurs and the provincial or territorial regulatory requirements.

Given the activities taking place in Canada to identify substances that are used in hydraulic fracturing and to monitor ongoing activities in other jurisdictions, and given existing provincial and territorial regulations, these uses will not be considered further in this assessment at this time. As information evolves, future activities may be considered by Environment and Climate Change Canada and Health Canada.

### **8.3.2.7 Agriculture**

Boron, an essential micronutrient for plants, is applied to soils to address nutrient deficiencies and is incorporated into some fertilizer pre-mixes to prevent nutrient deficiencies (Shubert 2003; [personal communication from CFIA 2014; unreferenced]). Boric acid precursors are used in Canada as boron micronutrients in fertilizers (see Section 5). According to CBSA (2013), between 1 000 000 and 2 400 000 kg of boric acid precursors were imported yearly into Canada between 2009 and 2012 by companies whose primary activity is agricultural chemicals.

Elevated boron concentrations in surface waters (median 3.1 mg B/L) and river waters (median 1.1 mg B/L) have been observed in the western San Joaquin Valley in California as a result of agricultural drain-water management practices, where shallow-lying saline groundwater (with elevated concentrations of boron) is directed away from fields to ensure crop productivity (Eisler 1990; Klasing and Pilch 1988; Ohlendorf 2002). Monitoring data for boron in surface water in Canada near intensive agricultural areas are scarce. However, water samples collected in July 2008 at 20 sites (including agricultural drainage ditches and streams) in Creston Valley, British Columbia (the

central Kootenay region's most significant agricultural area) found boron levels to be below the detection limit of 0.05 mg B/L (Davies 2008).

### **8.3.2.8 Pulp and paper manufacturing**

Between 2008 and 2012, multiple companies in the pulp and paper sector reported importing, purchasing or using boric acid precursors in their processes (CBSA 2013; Environment Canada 2009a, 2013a). Quantities imported or used yearly by a number of companies between 2008 and 2012 ranged from 0–100 kg to 100 000–1 000 000 kg of boric acid precursors (CBSA 2013; Environment Canada 2009a, 2013b). The substances are used as reducing agents to bleach wood pulps and recycled fibers (Ni et al. 2001; Wasshausen et al. 2006), and may be used in partial borate autocausticizing (Mao et al. 2006; Tran et al. 1999). Given that boron is an essential nutrient for plants and trees (Reiman and De Caritat 1998), it is naturally found in the raw materials (cell wall structure) processed in this sector. Therefore, boron releases to the environment might also occur from pulp and paper mills that do not directly use boric acid precursors in their manufacturing processes, but these releases are anticipated to be small. However, mills that use boron-containing substances are anticipated to release greater amounts to the environment, because the capture and removal of boron from wastewater treatment systems is low (Bryant and Pagoria 2004). Releases to surface water from pulp and paper mills' final effluents were identified as the principal source of boron to the environment for this sector.

Measured concentrations of boron in surface waters across Canada (obtained as part of the EEM program) for three pulp and paper mills (Environment Canada 2014m) are relatively low (Table 8-8). Due to the scarcity of environmental concentrations of boron available in receiving water bodies downstream of mills (exposed areas), PECs were also derived using available concentration data in mills' effluents. Average or median effluent concentrations were identified for 46 mills in Canada, and range from non-detected to 4.01 mg B/L (Environment Canada 2014m; Kovacs et al. 2007; Martel et al. 2010; MDDEP 2010b; NCASI 2006; UBC 1996). A high boron concentration value of 30.6 mg B/L reported in the final combined effluent of one facility (NCASI 2006) was determined to be erroneous. The correct average effluent concentration in effluent over the three-day monitoring event at the facility was 1.3 mg B/L (personal communication from MDDELCC 2014; unreferenced). Further details are available in Environment Canada (2014g). PECs were estimated for this sector by applying a default dilution factor of 10 to the average or median effluent concentrations reported at each facility and by adding the default background value of 0.031 mg B/L (see 8.3.2) to the resulting diluted effluent concentrations (see Table 8-8).

Because facilities using boron-containing substances are not necessarily captured in the available monitoring data, exposure modelling was also conducted for this sector. There are about 100 active mills in Canada that manufacture pulp (chemical, mechanical, thermo-mechanical and recycled), newsprint, printing/writing paper, tissue/towel paper, and paperboard. To account for differences in release rates for the

purpose of aquatic PEC calculations, these mills were divided into two groups: 34 tissue, towel and paperboard mills, and 66 pulp, paper and newsprint mills.

Conservative EACs for this sector were modelled using the highest release rates for each group based on available measured boron concentrations in mill effluents. These measured concentrations were obtained from 25 of the 100 active mills over the period 2001–2003 (NCASI 2006), and are assumed to be representative of the pulp and paper sector in Canada. The EACs of boron are in the range of 0.013–1.07 mg/L for tissue, towel and paperboard mills, and 0.029–1.4 mg/L for pulp, paper and newsprint mills. This corresponds to PECs ranging from 0.044–1.10 and 0.06–1.43 when considering background levels (see Table 8-8). Further details are available in Environment Canada (2014h).

**Table 8-8: Predicted environmental concentrations of boron for the pulp and paper sector**

Medium and units	PEC range	Number of samples (n=)	Sampling period	Reference
Water (mg B/L), reference station <sup>A</sup>	0.011–0.05	11	2009	Environment Canada 2014m
Water (mg B/L), exposed station <sup>A</sup>	0.011–0.05	16	2009	Environment Canada 2014m
Water based on effluent concentration (mg B/L) <sup>B</sup>	0.031–0.431	200	1994–2004	Kovacs et al. 2007; Martel et al. 2010; MDDEP 2010b; NCASI 2006; personal communication from MDDELCC 2014 (unreferenced); UBC 1996
Water, modelled (mg B/L)	0.044–1.43	-	-	Environment Canada 2014h

<sup>A</sup> Data for four facilities reporting to the EEM program (Environment Canada 2014m).

<sup>B</sup> The PEC range is based on median and mean effluent concentrations for 46 mills across Canada: one in British Columbia, one in New Brunswick, one in Ontario and 43 in Quebec. PECs were generated by applying a default dilution factor of 10 to the mean or median effluent concentration and by adding a default background value of 0.031 mg B/L.

### 8.3.2.9 Wastewater, down the drain releases, biosolids application and waste management

Wastewater treatment systems in municipalities represent a common point of entry for substances to surface water through effluent discharges. Also, the land application of wastewater biosolids is a potential point of entry to soil.

Empirical monitoring data are available for a number of wastewater treatment systems. For example, data were collected under the CMP monitoring program for 15 facilities

located across Canada from January 2011 to November 2012 (Environment Canada 2013c). A total of 72 influent samples, 18 primary effluent samples, and 72 final effluent samples were analyzed for total boron. Boron was detected in all but nine samples, with concentrations ranging from < 0.0011–2.1 mg B/L in the influent and < 0.0011–1.94 mg B/L in the final effluent. Median influent and effluent concentrations were 0.152 and 0.153 mg B/L, respectively. Assuming a dilution factor of 10, a range of concentrations in receiving water of < 0.00011–0.194 mg B/L is obtained for down-the-drain releases or their combination with industrial releases, and a range of PECs from 0.031–0.225 mg B/L is obtained when adding the aquatic background (i.e., 0.031 mg B/L) (see Table 8-9). Median removal of boron from influent to final effluent was negative 2.2% (i.e., effluent concentrations were greater than influent concentrations), indicating that little removal usually takes place. The increased boron concentration in effluent may be caused by the release of boron bound to organic matter following its degradation in biological treatments. Maximal removal of 83% observed at one facility could not be explained. Additional data for concentrations of boron in treated wastewater effluents identified for other locations throughout Canada between 1978 and 2012 range from < 0.01–0.7 mg B/L (Cain and Swain 1980; CWWA 2001; MDDEP 2001; Environment Canada 2013b; Swain et al. 1998).

Because releases of boron-containing substances to wastewater treatment systems are not necessarily captured in the available monitoring data, exposure modelling was also conducted for this sector. Several uses of boron-containing substances potentially resulting in down-the-drain releases contributing to the cumulative aquatic exposure to boron have been identified in Canada (CBSA 2013; Environment Canada 2009a, 2013b). Categories of products subject to down-the-drain releases include soaps and detergents, cosmetics, eye and personal care, swimming pool chemicals and veterinary products. Based on Canadian import data between 2009 and 2012 from companies involved in these categories of products, and U.S. annual quantities (for comparison purposes) for soaps and detergents, the annual quantity of substances used in products subject to down-the-drain releases is estimated to be approximately 650 000 kg B/year (Ball et al. 2012; CBSA 2013). A calculation combining information on quantities of boron reaching wastewater treatment systems and on removal efficiency for different wastewater treatment types (i.e., primary and secondary) with their effluent flows across Canada as well as receiving water bodies was used to estimate EACs. EACs calculated for these products range from negligible to 0.194 mg B/L, resulting in PECs ranging from 0.032–0.225 mg B/L, when adding background (0.031 mg B/L). The modelled PECs are similar to the PECs derived from measured concentrations in wastewater treatment effluents. Further details are available in Environment Canada (2014h).

Boron was also detected in most samples (64 of 81) of primary sludge, secondary sludge, and biosolids collected as part of CMP monitoring activities (Environment Canada 2013c). Concentrations in primary sludge, secondary sludge and biosolids ranged from < 0.03 to < 76 mg/kg dw (median of < 0.05 mg/kg dw), < 0.002–16.4 mg/kg dw (median of 6.03 mg/kg dw), and 0.03–445 mg/kg dw (median of 14.1 mg/kg dw), respectively (Environment Canada 2013c). The maximum concentration of 445 mg/kg could not be explained. Biosolids from wastewater treatment systems are sent to

landfills, incinerated or spread on agricultural land. The equation below was used to estimate the input of boron to soils via spreading of biosolids containing boron.

$$PEC_{added} = \frac{\text{boron concentration in biosolids} \times \text{application rate} \times \text{number of years}}{\text{mixing depth} \times \text{soil density}}$$

To simulate a worst-case scenario, a maximum application rate of 8300 kg dry weight per hectare (dw/ha) per year (based on the highest existing provincial regulatory limit; Environment Canada 2006), a mixing depth of 0.2 m (plough depth; ECHA 2012) and a soil density of 1200 kg/m<sup>3</sup> were used (Williams 1999), along with the highest concentration of boron measured in biosolids (37.6 mg/kg dw) from wastewater treatment systems in Canada, that are not incinerated. A period of 10 consecutive years was chosen as a length of accumulation (ECHA 2012). The cumulative boron concentration in soil at the end of this period is calculated to be 1.3 mg/kg dw. This  $PEC_{added}$  value is based on the assumption that boron will not leach or run off, nor be taken up by plants and removed through harvest, and is therefore conservative considering the high water solubility of boric acid.

Boric acid contained in products, manufactured items or other materials (e.g., contaminated soils) that are disposed of in landfills may leach out and end up in landfill leachate. Monitoring data were collected at 13 larger landfills across Canada between 2008 and 2013 under the CMP monitoring program. Total and dissolved boron concentrations were measured in leachate before and after treatment (when available). Before any treatment, total boron concentrations in leachate ranged from 0.001–42.1 mg B/L (median of 3.8 mg B/L; n=109) (Conestoga-Rovers and Associates 2015). Five of the 13 landfills treat their leachate on-site before either sending it to a wastewater treatment system or releasing it to the environment. For these landfills, total boron concentrations in leachate after treatment were 3.1–34.9 mg B/L (median of 15.3 mg B/L; n=25). Removal rates were generally low (11.3%), and in a few cases the concentration of boron in leachate was greater after treatment (Conestoga-Rovers and Associates 2015).

For landfills that send their leachate (treated or not) to a wastewater treatment system, the dilution of the leachate in the system's influent and dilution of the system's effluent in the receiving watercourse are expected to result in concentrations of boron below the levels of concern (PNEC) for aquatic ecosystems. Three landfills, however, release their leachate (treated or not) to the environment, to wetlands, a filtering marsh or directly to a river. Total boron concentrations measured in leachate (post-treatment if available) from 2008–2011 ranged from 0.8–5 mg B/L (n=6), from 3.1–6.1 mg B/L (n=6), and from 3.8–6.2 mg B/L (n=3). Using a dilution factor of 10 and adding 0.031 mg B/L for background yielded PECs of 0.11–0.65 mg B/L for all three sites.

**Table 8-9: Summary of predicted environmental concentrations as a result of wastewater effluent discharges, down-the-drain releases, land application of wastewater biosolids, and landfill leachate discharges**

Medium and units	PEC range	Number of samples (n=)	Sampling period	Reference
Water, from treated wastewater effluent concentrations (mg B/L) <sup>A</sup>	0.031–0.225	-	1978–2012	Environment Canada 2013c
Water, modelled for down-the-drain releases (mg B/L)	0.032–0.225			Environment Canada 2014h
Water, from landfill leachate concentrations (mg B/L) <sup>A</sup>	0.11–0.65	15	2008–2011	Conestoga-Rovers and Associates 2015
Soil (mg B/kg dw), from biosolids application	1.3	-	2009	Environment Canada 2013c

<sup>A</sup> Assuming a default dilution factor of 10 once reaching the receiving environment.

### 8.3.2.10 Rubber sector

Less than four rubber manufacturing companies imported between 10 000–100 000 to 100 000–1 000 000 kg/yr of boric acid precursors yearly into Canada from 2009–2012 (CBSA 2013), typically used as flame retardant in rubber products (Ball et al. 2012). Releases of boric acid from this sector are anticipated to be to the aquatic environment: facilities either release boric acid in their effluent to the receiving environment directly (direct dischargers) or indirectly via wastewater treatment systems (indirect dischargers).

EACs were calculated for direct dischargers and indirect dischargers, assuming that the maximum yearly quantity of boric acid imported into Canada for this sector is used at a single facility. EACs ranged from negligible (0.038 mg B/L for indirect dischargers) to a range of 0.03–0.29 mg B/L for direct dischargers. This leads to aquatic PECs of 0.032–0.26 mg B/L for indirect dischargers upon addition of the natural background concentration (0.031 mg B/L) and the concentration range ( $7.7 \times 10^{-4}$ –0.194 mg B/L) resulting from down-the-drain releases, and PECs of 0.06–0.32 mg B/L for direct dischargers with the addition of the natural background concentration only (0.031 mg B/L). Further details are available in Environment Canada (2014h).

### 8.3.2.11 Surface finishing

Boric acid precursors are imported into and used in Canada by surface finishing facilities (i.e., electroplating) (CBSA 2013; Environment Canada 2009a, 2013b), to clean substrate surface prior to plating and as a buffer in plating solutions. Boric acid also

serves other purposes such as promoting plating deposition and reducing passive film formation (Tsuru et al. 2002).

The highest annual known use quantity of boric acid precursors at an electroplating facility in Canada was reported to be in the range of 10 000–100 000 kg/yr (Environment Canada 2013b). The upper end value of 100 000 kg/yr was used to estimate the largest quantity used at a single facility discharging its treated wastewater to an off-site wastewater treatment system in a municipality, leading to an EAC of 0.095 mg B/L. When considering sources of down-the-drain releases and default background, a conservative aquatic PEC range of 0.13–0.32 mg B/L is obtained for this sector. Further details are available in Environment Canada (2014h).

### **8.3.2.12 Fibreglass insulation manufacturing**

Large quantities of boric acid precursors (1 000 000–10 000 000 to 10 000 000–50 000 000 kg) were annually imported, used or purchased by insulation fibreglass manufacturers in Canada from 2008–2012 (CBSA 2013; Environment Canada 2014n). The substances are used as flux to lower glass batch melting temperatures (Borax 2014a), increase mechanical strength and drawing quality (Woods 1994), impart decompressibility (Etimine 2014), and increase product insulation performance (Borax 2014a).

Impact upon vegetation as a result of boric acid precursors' air emissions has been observed in the vicinity of fibreglass manufacturing plants in Canada and Norway (Temple and Linzon 1976; Temple et al. 1978; Eriksson et al. 1981). Symptoms specific to boron toxicity observed on deciduous trees can include chlorosis and dark intercostal necrotic lesions of leaves (Eriksson et al. 1981; Temple et al. 1978). Emissions from the glass melting process can be particulates (boron oxides) or gaseous (as boric acid) (US EPA 1995; NPI 1998), and up to 15% of the boron added may volatilize during the manufacturing process (Wallenberger 2010). Emissions led to increased concentrations of boron in soil (a water-soluble boron concentration of 14.8 mg/L) and foliage (a maximum concentration of boron in foliage of 989 ppm) at the monitoring station located closest (150 m) to the Canadian facility (Temple et al. 1978). Uptake of boron was through direct absorption of gaseous or particulate boron into the foliage and from uptake of residual soluble boron in soil (Temple et al. 1978). Boric acid precursors were eliminated from the manufacturing process in the Canadian facility in 1973, bringing an end to emissions of boric acid precursors for this particular facility (Temple et al 1978).

Given that emissions of boric acid precursors and their uptake have been shown to harm vegetation, a conservative exposure scenario was developed to estimate increases in boron soil concentration related to the air emissions and resulting soil deposition of boron from currently operating fibreglass manufacturing sites (effects associated with direct absorption of boric acid precursors into foliage could not be modelled and are not captured by this analysis). A worst-case scenario was developed for a large Canadian facility using conservative emission rates and the program AERMOD, leading to a maximum steady-state  $PEC_{added}$  in soil of 1.3 mg B/kg based on

continuous release for 100 years (Environment Canada 2014l). Further details are available in Environment Canada (2014h).

Additionally, elevated boron concentrations (total boron of up to 114 mg B/kg and hot-water-soluble boron of up to 26.4 mg B/kg) have been observed in soil samples collected on the property of one facility that uses borax (Ontario MOE 2012). These elevated concentrations were hypothesized to be related to the presence of outdoor stockpiles of crushed glass (cullet) on the property or releases linked to a loading dock used to accept raw materials including borax (Ontario MOE 2012). Elevated soil concentrations seen on-site are, however, believed to be limited to property boundaries.

### **8.3.2.13 Generic scenarios**

Boric acid is used for purposes in addition to those already discussed. According to the CBSA (2013), these other uses can be broadly divided into large and small industrial users. The category of large industrial users comprises two main sectors having an annual cumulative import quantity of more than 1 million kg of boric acid precursors: agriculture products manufacturing, and construction products manufacturing (fibreglass insulation, cellulose insulation, engineered wood products and gypsum board). Boric acid and other precursors are used as flame retardant in cellulose insulation and engineered wood products (Borax 2014a; Lea 2000; Levan and Tran 1990). Boric acid is added during the manufacture of gypsum board to improve manufacturing processes, increase strength and enhance resistance to fire (Borax 2014b). Functions of boric acid precursors in agriculture and fibreglass insulation manufacturing are presented in sections 8.3.2.7 and 8.3.2.12, respectively. The category of small industrial users comprises various uses, with each having an annual import quantity well below 1 million kg (PECs were not estimated for these uses, but are expected to be lower than those from large users).

A total of 53 facilities were identified from import data obtained from the CBSA (CBSA 2013) and collected through a DSL IU (Environment Canada 2009a) for the large users' category. The facilities were further divided into three quantity groups:

Group I (21 facilities): use quantity per facility = 1000–100 000 kg/yr

Group II (28 facilities): use quantity per facility = 100 000–1 000 000 kg/yr

Group III (4 facilities): use quantity per facility = 1 000 000–10 000 000 kg/yr

Conservative EACs were calculated for indirect discharges to the environment from these manufacturing activities, by combining the daily release of boron based on the maximum use quantity of boric acid precursors selected for each group with daily dilution water volumes. Calculated EACs ranged from  $0.12 \times 10^{-3}$ –0.5 mg B/L, leading to PECs ranging from 0.032–0.725 mg B/L when adding background concentrations and sources of down-the-drain releases. Further details are available in Environment Canada (2014h).

## 8.4 Characterization of ecological risk

The approach taken in this ecological screening assessment was to examine the scientific literature, and develop conclusions based on a weight-of-evidence approach and using precaution as required under CEPA. Lines of evidence considered include results from risk quotient (RQ) analyses of key exposure scenarios, as well as information on fate, persistence, bioaccumulation, toxicity, and potential sources of boric acid releases to the Canadian environment. This section first presents the results of RQ analysis for exposure scenarios based on the various anthropogenic activities that may represent significant sources of release of boric acid to the environment. The PECs in the aquatic environment were based on measurements of boron in water or were modelled using conservative assumptions. Soil PEC<sub>added</sub>s were estimated by modelling the added concentration of boron in soil as a result of the deposition of boron on soil from air emissions or from land application of biosolids.

### 8.4.1 Risk quotient analysis

RQ analyses, integrating measured boron concentrations and realistic worst-case or conservative estimates of exposure with toxicity information, were performed for the aquatic environment and, in some cases, the terrestrial environment, to determine whether there is potential for boric acid to cause ecological harm in Canada. The exposure scenarios presented in Section 8.3.2 yielded negligible PECs ranging from negligible to 20.1 mg B/L in the aquatic environment and PEC<sub>added</sub> of 0.322 to 1.3 mg B/kg in soil. PNECs were derived for the aquatic environment (1.5 mg B/L), and a PNEC<sub>added</sub> value was derived for the terrestrial environment (6.08 mg B/kg) (see sections 8.2.1 and 8.2.3).

While the majority of the resulting RQs (PEC/PNEC) based on PEC ranges are below 1, RQ exceedances were identified in the aquatic environment for the metal mining sector and oil sands extraction and processing sector (Table 8-10). RQs within the metal mining sector were low for 68 sites (<0.6), while moderately high RQs of 0.68 - 0.78 and 0.15 - 0.86 were calculated for two sites (one mine / smelter and a uranium mill). However, elevated RQs of 9.7–13.4 were calculated at one milling site based on 14 samples over a 4 year period (2010-2013) indicative of high risk associated with aquatic releases of boric acid at this location.

Given that the oil sands extraction and processing sector's upper range PEC value of 1.72 mg B/L may reasonably be considered an outlier datapoint (see 8.3.2.5), the 95<sup>th</sup> percentile PEC value was used for comparison to the PNEC value, resulting in an RQ of 0.11. Although the upper end of the RQs for the pulp and paper sector is close to 1 (0.95), it is based on conservative assumptions for boron releases and limited to one site only, with the next-highest estimated RQ being 0.69. With the further refining of the pulp and paper exposure scenario, lower estimates for the RQs can be derived, although this is deemed not necessary at this time.

**Table 8-10: Summary of risk quotients obtained for different media and exposure scenarios for boric acid**

Sector	Medium	PNEC water (mg B/L); PNEC <sub>added</sub> soil (mg B/kg)	Range of PECs <sup>A</sup> water (mg B/L); PEC <sub>added</sub> soil (mg B/kg)	Range of RQs
Power generation	Water	1.5	0.786–1.0	0.52–0.67
Power generation	Soil	6.08	0.322	0.053
Metal mining	Water	1.5	Negligible–20.1	0–13.4
Smelting and refining	Water	1.5	Negligible–1.17	0–0.78
Coal mining	Water	1.5	0.004–0.061	0–0.04
Oil sands extraction and processing	Water	1.5	0.0001–1.7; 0.16 <sup>B</sup>	0–1.13; 0.11 <sup>C</sup>
Oil sands extraction and processing	Soil	6.08	0.92	0.15
Agriculture	Water	1.5	< 0.05	0
Pulp and paper	Water	1.5	0.011–1.43	0.007–0.95
Wastewater and down-the-drain releases	Water	1.5	0.031–0.225	0.02–0.15
Waste management (landfill leachate)	Water	1.5	0.11–0.65	0.07–0.43
Biosolids application	Soil	6.08	1.3	0.21
Rubber sector	Water	1.5	0.032–0.32	0.02–0.21
Electroplating	Water	1.5	0.125–0.32	0.08–0.21
Fibreglass manufacturing	Soil	6.08	1.3	0.21
Generic scenarios	Water	1.5	0.032–0.725	0.02–0.48

<sup>A</sup> Based on dissolved boron concentrations when available.

<sup>B</sup> PEC based on the 95<sup>th</sup> percentile dissolved boron concentration calculated for “tests” station (n=590) sampled as part of RAMP (2014), where a single dissolved boron concentration value of 1.7 mg B/L above PNEC was measured.

<sup>C</sup> RQ calculated using a PEC based on the 95<sup>th</sup> percentile dissolved boron concentration for “tests” station

#### 8.4.2 Consideration of lines of evidence and conclusion

This screening assessment includes all substances having the potential to dissolve, dissociate or degrade to release boric acid through various transformation pathways

that can potentially contribute to the combined exposure of ecological receptors to boric acid (boric acid precursors). Sources of boric acid include activities involving boric acid precursors (including the 14 boron-containing substances that had been identified as meeting the categorization criteria) having the potential to release boric acid, as well as incidental manufacture and natural/ambient background concentration of boric acid. Efforts were made throughout this ecological assessment to focus on all sources of boric acid and link assessment endpoints and exposure scenarios to the industrial activities involving them, to the extent possible. Data on manufacture, import and use of specific substances were used, where possible, to model releases in order to estimate PECs. As well, other anthropogenic incidental sources of boric acid to the environment were systematically included, using sector analyses and through the use of monitoring data to estimate PECs.

Once released into the environment, boric acid is expected to be persistent in water, soil and sediment. Boric acid has been demonstrated to have low to moderate toxicity to sensitive aquatic and terrestrial organisms. The bioaccumulation potential of boric acid is low in most organisms, and does not generally lead to levels causing harm to sensitive species at body concentrations higher than required for essentiality.

This assessment of boric acid and its precursors examined exposures from a wide range of sources covering multiple substances that could contribute to loadings of boric acid in the environment. Generally, the data indicate that anthropogenic releases of boric acid, either through the import and inferred uses of boric acid and its precursors or as a result of incidental releases from a number of industrial activities, are not expected to result in concentrations of boric acid at levels higher than effects threshold concentrations in the Canadian environment (water and soil) for most sectors of activity. However, one location or area of concern for aquatic organisms was identified for metal mining, with high RQs for that site (an ore milling facility) ranging from 9.7–13.4, and RQs of up to 0.78 and 0.86 were also calculated for two other sites within this sector including one combined mine and smelter site and one uranium mill. Based on these findings and other supporting information from Paliewicz *et al* (2015) regarding the high leachability of boron in slags from precious metal recovery, it is reasonable to assume that other facilities engaged in similar activities could release elevated concentrations of boric acid to the aquatic environment.

Considering all lines of evidence above, there is a risk of harm to organisms, but not to the broader integrity of the environment, from boric acid, its salts and its precursors. It is therefore proposed to conclude that boric acid, its salts and its precursors meet the criteria under paragraph 64(a) of CEPA as they are entering or may enter the environment in a quantity or concentration or under conditions that have or may have an immediate or long-term harmful effect on the environment or its biological diversity. However, it is proposed to conclude that boric acid, its salts and its precursors do not meet the criteria under paragraph 64(b) of CEPA as they are not entering the environment in a quantity or concentration or under conditions that constitute or may constitute a danger to the environment on which life depends.

### 8.4.3 Uncertainties in evaluation of ecological risk

Boric acid is a well-characterized substance in terms of its ecotoxicological properties. The CCME water quality guideline published in 2009 was found to appropriately represent the aquatic PNEC for boric acid, because a review of the literature concluded that no studies published since that time have presented evidence for higher toxicity. Some uncertainty was noted in the data for effects to sediment organisms. Experimental difficulties were noted in achieving and maintaining exposure concentrations within sediment, due to the tendency of boric acid to partition back into the water phase. Based on the NOEC values for spiked water tests being much larger than the aquatic PNEC, the aquatic PNEC was deemed to be protective of sediment organisms exposed to pore-water concentrations of boric acid. Because of the low partitioning of added boric acid to soil, the absence of soil-aging effects, and the low bioavailability of boron in natural soil, the added risk approach was used to derive a soil PNEC<sub>added</sub>. The added risk approach assumes that only the anthropogenic added fraction of boric acid contributes to risks, thereby ignoring the possible contribution of natural background concentration to toxic effects. Although the contribution of natural background concentration to toxic effects is anticipated to be low, conservative assumptions (e.g., no loss via run-off, leaching, or uptake by plants) were used when generating model soil PEC<sub>added</sub> as a precaution. A rich dataset of high-quality chronic soil-toxicity studies for 23 species, including many boreal species found in Canada, was employed to derive the soil PNEC<sub>added</sub> from a species sensitivity distribution. The dataset met species coverage requirements suggested by domestic (CCME) and international (MERAG) guidance. Uncertainty in the ecological effects data is expected to be low.

Due to widespread use across a majority of sectors, including incidental manufacture in many sectors, uncertainties were noted in the exposure component of the ecological risk assessment. Exposure scenarios were developed for the major sectors that either use boric acid precursors or that are implicated in their incidental manufacture. Major sectors were identified on the basis of quantity of substances used, or of high concentrations identified in available monitoring data, given that these variables were more likely to be directly correlated with releases to the environment. Although some uncertainty is introduced by this approach, PECs for the remaining uses were calculated using a very conservative generic scenario.

Import data from the CBSA were used to supplement findings from the DSL IU and voluntary stakeholder engagement, in order to characterize the sectors with the largest involvement with boric acid precursors by quantity. Importers were assigned to a sector by making assumptions about the importer's primary activity based on publicly available information or by correlating with DSL IU submissions or voluntary stakeholder engagement. An additional uncertainty arises from the fact that the CBSA data are organized by HS codes, which in several cases describe groups of substances (e.g., metal borates). Thus, in some instances, an HS code-based import quantity could comprise unknown quantities of several different substances. To address this uncertainty, and because quantities required conversion to boron equivalents for comparison to the derived PNECs, a conservative assumption was made that all HS

code-based import quantities would be treated as boric acid. Boric acid has the highest boron content (17.5%) among the major commercial boron-containing substances (e.g., borax pentahydrate, borax decahydrate), while the majority of other boric acid precursors are also below this value.

PEC calculations for sectors using boric acid precursors were performed under the assumption that users from different sectors were not releasing to the same wastewater treatment facility or surface water body. If the maximum modelled aquatic PEC values were added for multiple sectors, a resulting combined PEC could potentially exceed the aquatic PNEC. However, based on the CBSA data (which contains addresses), voluntary stakeholder engagement, and DSL IU results, it can be concluded that such “combined release” would be unlikely to result in ecological risk at present. Some uncertainty remains, with the potential for relocation of users or introduction of new users to result in combined releases. However, from a probabilistic standpoint, it appears a rare occurrence for multiple users to all be at the maximum of the exposure distribution for their sector at the same time and place. Additionally, the exposure calculations were conservative.

Aquatic concentrations of boron in the receiving environment (i.e. downstream from effluent discharge) were available for approximately 60% of metal mining sites. While this does not present a full picture of boron releases from the mining sector in Canada, the available data is recent and considered highly reliable. There is however uncertainty, and therefore potential concern, for sites similar to the site showing high risk and those with RQs approaching one.

One measured environmental concentration at one location for the oil sands extraction and processing sector was in excess of the aquatic PNEC. The value was reasonably assumed to represent statistical outliers, because 95<sup>th</sup> percentiles and/or median values were found to be well below the aquatic PNEC. This was only the case for this sector, and the outlier was deemed to carry insufficient weight to alter the ecological conclusion. However, environmental concentrations should continue to be measured and analyzed for this sector to ensure that high concentration values truly are, and remain, outliers.

Overall, uncertainty in the exposure characterization may be larger than the effects characterization for the ecological risk assessment. However, based on mitigation by a number of conservative assumptions, the impact on the conclusion is minimal.

## 9. Potential to Cause Harm to Human Health

### 9.1 Health effects assessment

Boric acid, its salts and its precursors are considered toxicologically equivalent. As such, dose levels between studies conducted with boric acid, its salts or its precursors were standardized to boron equivalents. Given that the health effects of boric acid have previously been reviewed by Health Canada's PMRA (Health Canada 2012), the scope of this section is limited to a review of the human studies that were not included in the PMRA Re-evaluation of Boric Acid and its Salts, which focused on pesticidal applications.

Health Canada (2012) previously established a benchmark dose level (BMDL) of 2.90 mg B/kg bw/d, which was derived from two dog toxicity studies. This BMDL was based on testicular weight changes with histological indications of toxicity. Other assessments (WHO 2003, 2009; US EPA 2004; ATSDR 2010; EFSA 2013) are based on a no observed adverse effect level (NOAEL) of 9.6 mg B/kg bw/d that is based on developmental toxicity in a rat study (see Appendix H).

#### International classification

A number of boric acid precursors were classified by the European Union (European Commission 2008) as Category 1 reproductive toxicants. In addition, sodium perborate monohydrate and tetrahydrate were classified as causing "risk of serious damage to eyes," and sodium tetraborates were classified as eye irritants under European Commission guidelines 67/548/EEC (European Commission 2009).

#### Toxicokinetics of boric acid

Boric acid and borates were readily and near completely absorbed by humans and rats following oral ingestion, as indicated by the changes of boron levels in urine, blood and tissues. In human volunteers, over 90% of the administered dose was excreted in the urine over a 96-hour period after oral exposure (Schou et al. 1984; Jansen et al. 1984a). In rats, 95% and 4% of the administered dose was recovered from urine and feces, respectively, within 24 hours of exposure (Vanderpool et al. 1994). A 100% inhalation absorption rate as worst-case assumption was applied by ATSDR (2010) and Austria (2008a) for the risk assessment of boron compounds.

Borates have been demonstrated as being able to penetrate damaged or abraded skin (Draize and Kelley 1959; Nielsen 1970; Stüttgen et al. 1982; EU 2007a). Wester et al. (1998a) reported on the *in vivo* percutaneous absorption of boric acid precursors. Volunteers (eight per group) were dosed (non-occluded) with boric acid (5%), borax (5%) or disodium tetraborate decahydrate (10%) in aqueous solution. Both pre-treatment urine on days 1–4 and post-treatment urine up to day 17 were collected. On

days 5 and 12, the test chemical was applied to the back area of individuals; the day 12 exposure was pre-treated with sodium lauryl sulphate to mimic potentially irritated skin. The chemical remained on the skin for 24 hours, at which point the remaining chemical was removed via skin washes. The dermal absorption rate was calculated based on comparing applied dose to detected boron levels in 24-hour urine samples that were collected daily for 17 days. Chemical losses to outside clothing and bedding were not corrected in the reported study results. The mean percentage absorbed (standard deviation) was reported to be 0.226% ( $\pm$  0.125), 0.210% ( $\pm$  0.194) and 0.122% ( $\pm$  0.108) for boric acid, borax and disodium octaborate, respectively (Wester et al. 1998a). Based on the amount of test chemical recovered from the skin washes, the average corrected dermal absorption ranged from approximately 2–4% for the three groups and two doses studied.

In addition to *in vivo* absorption, Wester et al. (1998b) studied the *in vitro* percutaneous absorption of boric acid (0.05–5%), borax (5%) and disodium octaborate tetrahydrate (10%) through human skin. The study reported permeability coefficient ( $K_p$ ) values ranging from  $1.4 \times 10^{-6}$ – $5.0 \times 10^{-4}$  centimetres per hour (cm/h).

These studies have been considered by the European Commission Scientific Committee on Consumer Safety (SCCS 2010a, 2010b) and Health Canada (2012) to estimate dermal penetration or establish default dermal absorption values. The SCCS derived a dermal absorption of 0.5% based on Wester et al. (1998a), which is two standard deviations above the 0.226% absorption reported for boric acid. In Health Canada (2012a), due to limitations in the studies including a low mass balance recovery, a dermal absorption of 50% was used. In the current assessment, dermal absorption is estimated using a range of dermal absorption values, i.e., 0.5% at the low end and 10% at the high end, to account for the above-noted study limitations. In addition, the current assessment uses the highest reported  $K_p$  ( $5.0 \times 10^{-4}$  cm/h) from Wester et al. (1998b) to estimate exposure in infinite-dose scenarios (e.g., swimming in pools). In the absence of adequate studies to quantify absorption across broken skin, absorption across broken or abraded skin was considered to be 100% in this assessment.

Absorbed boron is distributed rapidly and evenly throughout the body's soft tissues, with slight accumulation in bone (2–3 times higher than soft tissue), as demonstrated in experimental rats and occupationally exposed workers (Culver et al. 1993, 1994; Jansen et al. 1984a, 1984b; Treinen and Chapin 1991; Ku et al. 1991). Studies indicate that boric acid has a strong affinity for cis-hydroxyl groups (this effect is reversible and concentration-dependent) (WHO 1998), which may explain the higher concentrations of boric acid in bone (EU 2007a).

Boric acid is not metabolized in animals or humans due to the high energy level required (523 kilojoules per mole [kJ/mol]) to break the boron-oxygen bond (Emsley 1989). Other inorganic borates convert to boric acid at physiological pH in the aqueous layer overlying the mucosal surfaces prior to absorption.

In humans, rats and rabbits, boron is mainly excreted in urine in an ionized form, regardless of the route of administration, with only 2–5% lost in feces (Jansen et al. 1984b; Usuda et al. 1998; Draize and Kelley 1959). Reabsorption of boron from kidney tubules may occur in humans at low doses (Murray and Schlekot 2004). The elimination half-life was estimated to be approximately one hour for mice and less than 12 hours for rats (Farr and Konikowski 1963; Ku et al. 1991, 1993a, 1993b). At the high dose level, the urinary boron clearance was slightly higher in pregnant than non-pregnant rats (US Borax 2000; Vaziri et al. 2001). The mean plasma half-life of boric acid was determined to be 13.4 hours (a range of 4.0–27.8 hours) in humans who were accidentally exposed to boric acid (Litovitz et al. 1988). Similarly, pregnant women clear boron more effectively than non-pregnant women ( $1.02 \pm 0.55$  vs  $0.80 \pm 0.31$  mL/min/kg-bw, respectively), which is consistent with increased measures of renal function in humans during pregnancy (Pahl et al. 2001). There is evidence to suggest that boron is able to cross the placenta (Grella et al. 1976; Harari et al. 2012).

### **Acute toxicity, irritation and sensitization**

Symptoms of acute oral toxicity found in humans typically include depression, ataxia, convulsions and death. Eye irritation and respiratory symptoms were significantly associated with workers exposed to boron dust (boric acid, borax or boron oxide) (Garabrant et al. 1984; Wegman et al. 1991, 1994; Cain et al. 2004, 2008).

### **Human epidemiological studies and case reports**

#### *Epidemiological studies*

Similar to the opinion issued by the Committee for Risk Assessment of the European Chemicals Agency (ECHA) (ECHA 2014), the current evaluation has determined that the available epidemiology studies are not of sufficient quality to select points of departure for risk assessment. The studies have shortcomings, including small sample size, limited consideration of confounders, and limited evaluation of health end-points. Indications of toxicity were noted in many animal studies, in the form of histopathological changes in the testes; similar investigations are not available with human subjects. Although the suite of human studies demonstrate less overt toxicity than animal studies, they were conducted at lower exposure levels and therefore do not reduce confidence in the animal database. Thus, the limitations in these studies preclude their use in the quantification of risk.

In several studies where boron has been administered to human volunteers, there have been suggestions of a beneficial effect on calcium retention, lean body mass and free testosterone levels (Naghii et al. 2011; Hasbahceci et al. 2013; Nielsen et al. 1987). However, in some studies, doses as low as 3 mg/d (assumed to be 43 µg/kg bw/d based on an assumed body weight of 70 kg) resulted in changes in blood pressure and the shape of the QRS complex (from electrocardiogram recordings) (Hunt et al. 1997). Other authors have reported an increase in menopause symptoms (hot flashes and night sweats) in women dosed with 2.5 mg boron per day (plasma boron concentrations

were elevated to a mean of 0.053 µg/mL from the control concentration of 0.034 µg/mL). Changes in circulating oestradiol and white blood cell counts were also noted in this study (Nielsen and Penland 1999). The endocrine modulation effects of boron supplementation are of concern, and these endocrine effects have not been adequately investigated in animal experiments.

In worker studies, several authors reported an absence of toxicological effects from high boron exposures. However, some authors have identified a range of health outcomes, including abortions, delayed pregnancy and an alteration in male-to-female offspring sex ratio. Although the overall database is insufficient to identify points of departure for risk characterization, as noted below there are potential indications of adverse health outcomes from high boron exposures.

Reproductive history, including (primarily) infertility, parity of sex in offspring, birth defects, spontaneous abortions, prenatal mortality and developmental disabilities, were investigated by interview or questionnaire among workers in boron industries within the United States, Turkey and China (reviewed by Scialli et al. 2010). A survey by Whorton et al. (1994a, 1994b) conducted in 542 married, male boron workers from Boron, California showed that the live birth rates in the wives of boron workers were significantly higher than the U.S. Standardized Birth Ratio after adjusting confounders (529 vs. 466.6,  $p < 0.01$ ). However, an excess of female offspring numbers almost reached statistical significance in boron workers compared to that of the national standard (52.7% in workers vs. 48.8% of the national standard). As noted below, changes in offspring sex ratio represent the most common finding in human studies; however, it is of unknown toxicological significance.

In a study of female boron workers (Whorton et al. 1992, cited in US EPA IRIS 2004, no detail available), a reduced offspring delivery rate was recorded in 68 participants (34.5 expected, 32 delivered). Although the reduction was not significant, the United States Environmental Protection Agency (U.S. EPA) (US EPA 2004) claimed that this may indicate a deficiency in birth rate. Another study of 904 female workers in semiconductor industries, by Swan et al. (1995), showed that the risk of spontaneous abortion was increased among subgroups that experienced a low level of boron exposure at work compared with other workers without exposure. Several studies were conducted by Sayli and colleagues in boron-exposed populations in Turkey to investigate the correlation between boron exposure and impaired fertility in subpopulations living in regions with varied boron concentrations in the environment; there were no significant differences in primary infertility rates reported in residents living in different regions (2.34% in high-boron regions vs. 2.62% in low-boron regions) (Sayli 1998), but the sex ratio (male: female) at birth in the high-boron regions was reported to be lower than that of regions far away from the high boron area (0.995 vs. 1.37). The female-favoured sex ratio of offspring was also identified in a follow-up study by Sayli et al. (1998). As part of Sayli's investigation, a survey conducted by Tüccar et al. (1998) did not reveal significant differences in spontaneous abortion rate or stillbirth rate among subgroups in high- or low-boron regions. Similarly, Sayli (2001, 2003), Sayli et al. (2003) and Cöl et al. (2000) did not identify a significant difference in infertility rate or reproductive history

between boron workers and non-boron workers in Turkey. However, a similar survey conducted among wives of 945 boron workers and wives of 249 control workers from a boron plant in Liaoning, China (Liu et al. 2005a) revealed that the prevalence of spontaneous abortion (5.74% in workers vs. 3.30% in controls,  $p < 0.05$ ) and delayed pregnancy (5.07% vs. 3.07%, not significant) among the wives of boron workers were all higher than those of local control groups after adjusting for the potential confounders. The sex ratio at birth among workers was slightly lower than that of controls and the provincial and national ratios (1.09, 1.18, 1.12 and 1.16, respectively). In another study conducted at the same mining site in China, although not statistically significant, boron workers showed greater delay in pregnancy among wives of 936 boron workers compared to that of 251 controls (9.42% in workers and 4.62% in controls; Chang et al. 2006). The number of spontaneous miscarriages was found to be higher among boron workers (7.71% vs. 4.92%), whereas the sex ratio was lower in boron workers (52.45% male offspring among boron workers vs. 54.35% among controls). Daily boron exposure was estimated as 0.06–51.07 mg in boron workers and 0.005–0.016 mg in comparison groups in this study, based on occupational exposure limit via inhalation route. A slightly lower, but not statistically significant, sex ratio at birth was also reported in the offspring of men living in the area of Northern France where the boron drinking-water level was approximately 0.30 mg B/L compared to the men from a relatively low-boron area (Yazbeck et al. 2005).

Despite the general methodological limitations and the variation in considering the lifestyle, social and cultural influences in the epidemiological studies discussed above, the altered sex ratio at birth (female-favoured) was observed in several studies among high boron-exposure groups. Although the mechanism by which boron exposure may change the sex ratio has not yet been established, studies in humans and animals reviewed by Terrell et al. (2011) on several reproductive toxicants, including boron, have found an association between the reduction in the number of male births and chemical exposure.

The relationship between boron exposure and sperm parameters, such as sperm count, sperm motility and morphology, sperm DNA integrity and X- to Y-bearing sperm ratio, was investigated in various studies among boron workers in Russia, Turkey and China. The results of an early Russian study showed that reduced sperm count, sperm motility and elevated fructose content of seminal fluid were found in 6 of 28 male boron workers exposed to 22–80 mg/m<sup>3</sup> of borax vapour and aerosol via inhalation for more than 10 years; however, the number of pregnancies among their wives was not affected (Tarasenko et al. 1972). Sperm quality and blood hormone levels were further inspected in 102 boron workers and 102 controls in Bandirma, Turkey by Duydu et al. (2011) and Basaran et al. (2012). There were no significant differences in blood hormone levels (FSH, LH or testosterone) or sperm parameters between the high- and low-blood boron groups ( $P > 0.05$ ). In addition, the DNA integrity of sperm, as indicated by the tail intensity between the groups, was statistically not different ( $P > 0.05$ ) for both alkaline and neutral COMET assays (Duydu et al. 2012). The highest daily boron exposure in air, water and food was estimated as a mean of  $14.45 \pm 6.57$  mg/d (range 3.32–35.62) in boron workers. However, the daily boron intake derived from urine boron analysis in a

similar study in Turkey was reported as 1.4 mg B/d and 6.5 mg B/d in control and exposure groups, respectively (Korkmaz et al. 2011). A sperm parameter study has also been conducted in northern Chile, in communities with high boron levels in drinking water. Espinoza-Navarro et al. (2010) found that the sperm mortality among 102 healthy young male residents was low, but only 38.3% of participants had sperm quality sufficient to meet criteria established by the World Health Organization (WHO) (1999).

A study conducted in Liaoning, China by Liu et al (2005b) found that the sperm viability, motility, path velocity and progressive velocity in 60 boron workers were significantly lower than that of nine controls, even after confounder adjustment. The mean daily intake of boron (diet, water  $\pm$  air dust) was estimated as 19.79 mg/d (equivalent to 0.28 mg B/kg bw/d) in boron workers and 1.53 mg/d in controls. However, similar health effects were not identified in extended cohorts in later studies by the same author (Liu et al. 2006a, 2006b). The reproductive history and sperm quality in a cohort in the same area in China were later investigated again by Robbins et al. (2010) and Robbins (2008). The only effect noted was a lower ratio of Y- to X-bearing sperm in boron workers compared to men not working in the boron industry. However, the correlations between the biological boron measures and the Y:X-bearing sperm ratios within groups were not statistically significant (Robbins et al. 2010). The total daily boron exposure was estimated as (mean  $\pm$  SD) 41.2  $\pm$  37.4, 4.3  $\pm$  3.1 and 2.3  $\pm$  3.0 mg in boron workers, community controls and remote area controls, respectively (Robbins et al. 2008). The highest estimated boron daily intake derived from these studies was 41.2 mg/d (equivalent to 0.6 mg B/kg bw/d).

Boron exposure via inhalation in humans is mainly limited to the occupational setting. A cross-sectional study of respiratory effects was performed by Ury (1966) in male workers at the borax plant in California, and the result showed that, among the 629 men who experienced over a year of work-related exposure to sodium borate dehydrate dust, 82 showed some evidence of respiratory effects. Occupational exposure to boron oxide and/or boric acid via inhalation also induced eye irritation, dryness of mouth, nose or throat, sore throat, and productive cough.

### *Essentiality in humans*

The body of evidence has yet to establish a clear biological function for boron in humans (IOM 2001). The use of boron as a dietary supplement has not been endorsed by the U.S. Food and Nutrition Board/Institute of Medicine (ATSDR 2010); the European Food Safety Authority concluded that the cause and effect relationships have not been established between the consumption of boron and the maintenance of normal bone or joints, maintenance of normal thyroid function, or contribution to normal cognitive function (EFSA 2011a, 2011b); and boron has not been established to be an essential nutrient for humans, nor has a biochemical function for boron been identified in most animal species studied or in humans (EFSA 2004).

### *Case reports*

Early case reports have shown death in newborns within five days of ingesting less than 3 g of boric acid (Young 1949, cited in Health Canada 2012). Boron-induced convulsions and seizures have been associated with infants accidentally exposed to honey-borax mixture in their diet at 429–1287 mg/d for 4–10 weeks or at 125 mg borax for over three months (O'Sullivan and Taylor 1983; Gordon et al. 1973). Repeated dermal application of baby powder containing boric acid induced cutaneous lesions, seizures and gastrointestinal disturbances in infant poisoning cases (Goldbloom and Goldbloom 1953). Dermatitis, alopecia and indigestion were observed in patients receiving 5 mg B/kg bw/d or more (route not clear) when boron was used for the chronic treatment (over two years) of epilepsy. When the dose was reduced to 2.5 mg B/kg bw/d, the toxic signs and symptoms disappeared (Culver and Hubbard 1996).

## 9.2 Exposure assessment

Given that boric acid is a naturally occurring substance and is ubiquitous in environmental media, it is present in food, drinking water, air, soil and dust. Boric acid is also a common ingredient in a wide range of products used by Canadians. All of these sources contribute to total daily exposure. As noted previously, measurements of boric acid in environmental media, products and humans in this assessment are expressed in terms of total boron, and exposure estimates are expressed as mass of boron per mass of body weight (bw).

### Environmental media, food and drinking water

#### *Air*

Boron concentrations in ambient air are less commonly measured than other inorganic elements. In Canada, Health Canada has conducted studies that reported concentrations of total boron present in PM collected in indoor, outdoor and personal air samples. Specifically, boron air concentrations are available for Windsor, Ontario; Halifax, Nova Scotia; and Calgary and Edmonton, Alberta. Median concentrations of boron measured in indoor and outdoor fine PM samples (PM<sub>1</sub>) collected in residential areas of Edmonton, Calgary and Halifax were < 5 nanograms per cubic metre (ng/m<sup>3</sup>) (n=262) (Health Canada 2013a, 2013b, 2013c). The median and 95<sup>th</sup> percentile concentrations of boron in coarse PM samples (PM<sub>10</sub>) measured in Windsor in 2005 and 2006 were 5.3 and 17.6 ng/m<sup>3</sup> in personal samples, 5.3 and 21.0 ng/m<sup>3</sup> in indoor samples, and 12.1 and 34.3 ng/m<sup>3</sup> in outdoor samples, respectively (Rasmussen et al. 2013). Overall, boron concentrations measured in PM in residential areas are low—in the ng/m<sup>3</sup> range.

#### *Soil and dust*

There are over 200 minerals containing boron oxide, with the four most important boron-containing minerals being borax, kernite, colemite and ulexite (USGS 2013). The highest concentrations of boron are found in sediments and sedimentary rock, particularly clay-rich marine sediments (Moss and Nagpal 2003). Boron is naturally

released to soil by rainfall, weathering of boron-containing minerals, desorption from clays, and decomposition of boron-containing organic matter (ATSDR 2010). Most boron compounds are transformed to borates in soil due to the presence of moisture; borates themselves are not further degraded in soil (ATSDR 2010). Boron is an essential nutrient for plant growth, and boron is taken up by plants as boric acid (Penny 2004). Boron retention in soil depends on boron concentration in the soil solution, soil pH, texture, organic matter, cation exchange capacity, type of clay, and mineral coating on the clay. Anthropogenic sources of boron to soil include the application of boron-containing fertilizers; application of fly ash, wastewater or biosolids as a soil amendment; the use of wastewater for irrigation; and land disposal of boron-containing industrial wastes (ATSDR 2010). There are limited data characterizing the concentration of boron in soil in Canada. Reported total boron soil concentrations from residential, agricultural and industrial areas range from 1–90 mg/kg (BC MOE 2005; Agriculture and Agri-Food Canada 2013; Government of New Brunswick 2005; Penny 2004; Jacques Whitford AXYS 2008). Average boron soil concentration in the United States is 33 mg/kg, ranging from < 20–300 mg/kg (USGS 1984). These data are discussed in more detail in Section 8.3.1.2.

Nationally representative bioaccessible boron concentrations from Canadian homes were available from the Canadian House Dust Study (Rasmussen et al. 2013). This study reported bioaccessible boron concentrations (measured in simulated stomach fluids) ranging from 7–2091 mg/kg with a median concentration of 65.3 mg/kg (n=1025) (Rasmussen et al. 2013). Sources of boron in household dust include the use of boric acid in building materials (e.g., wood, cellulose insulation), products that contain boron substances (e.g., cleaning products, pesticides), and tracked-in soil.

#### *Food and drinking water*

The most common source of daily exposure for Canadians is ingestion of boron from food. Boron is a microessential nutrient for plant growth, meaning boron enters the food chain through plants. According to research, within the intestinal tract, most ingested boron is believed to convert to boric acid, the normal end product of hydrolysis of most boron compounds, and is available for absorption (Hunt et al. 1997, 2004; Hunt 2006). The natural boron content of foods varies considerably depending on various factors, including the concentration of boron in the underlying soil, the soil properties, and the requirements of the plant. Little is known about the speciation or bioavailability of boron in natural foodstuffs (Hunt et al. 2004). Anthropogenic inputs of boron into the food chain include intentional inputs from the use of boron-containing fertilizers and unintentional inputs from food packaging (in adhesives, paper and paperboard). Industrial point sources (e.g., leaching) and agricultural run-off can also be a source of boron in the food chain.

Total boron was measured in over 30 000 food samples collected as part of various monitoring programs conducted by the Canadian Food Inspection Agency (CFIA), including the National Chemical Residue Monitoring Program (2008–2009 and 2009–2010), the Children’s Food Project (2008–2009 and 2010–2011) and the Food Safety

Action Plan (2009–2013) (as described in CFIA 2014). The highest average total boron concentrations in foods, as purchased, were in baking ingredients at 25 µg/g, nut butters at 16 µg/g, herbs and spices at 14 µg/g, beverages at 12 µg/g, seed butters (sunflower and tahini) at 10 µg/g, and vegetable proteins at 10 µg/g. Fruits and vegetables had average concentrations of 3 and 4 µg/g, respectively, while grains, dairy and meat all had lower average concentrations of 1.5, 0.2 and 0.06 µg/g, respectively (CFIA 2014). Boron is present in breast milk; an average concentration of 30 µg/L total boron was measured in breast milk from 10 mothers in Newfoundland (Hunt et al. 2004).

In Canada, total boron is commonly measured at water treatment facilities and in distribution systems for drinking water. Total boron concentration data were available from Newfoundland and Labrador, New Brunswick, Quebec, Ontario, Manitoba, Saskatchewan and the Yukon Territory (2013 email from the Water and Air Quality Bureau, Health Canada, to the Existing Substances Risk Assessment Bureau, Health Canada; unreferenced). Typical concentrations of total boron ranged from < 5 to 150 µg/L. In over 30 000 samples reported, there were 2 exceedances of the Health Canada drinking water guideline of 5000 µg/L. Concentrations of total boron in well water may be higher and more variable than in surface waters, due to natural leaching from rocks (Health Canada 1990). Boron concentrations in groundwater (and hence well water) are typically higher in regions composed of sedimentary rocks (these conditions are present in the Prairie provinces).

Probabilistic dietary intake estimates for the general population were derived by Health Canada's Food Directorate, using concentrations of total boron in food commodities collected from 2009–2013 and from provincial drinking water data. Consumption estimates were based on data from the Canadian Community Health Survey, Cycle 2.2 on Nutrition (Statistics Canada 2004), including intake of drinking water. When possible, the CFIA imported and domestic mean boron concentration values were combined. In the case of drinking water, log-normal distributions were fitted to the water concentration data for each of the provinces, and boron concentration values were randomly generated from log-normal distributions with the parameter estimates for the corresponding province (NL, NB, QC, ON, MB, SK, YT).

Median dietary intakes (food and drinking water) ranged from 20.4–91.7 µg B/kg bw/d, and 95<sup>th</sup> percentile intakes ranged from 41.5–182.6 µg B/kg bw/d (Table 9-1). The highest dietary intakes occurred in children aged 1–3, while the lowest dietary intakes occurred in males aged 71 and older. Fruits (e.g., apples), fruit juice and vegetables (e.g., carrots, tomatoes) were the primary contributors to dietary intake, accounting for 41–62% of dietary intake depending on the age group. Drinking water (tap and bottled) accounted for 3–16% of dietary intake. Intake for breastfed infants (aged < 6 months) is estimated to be 3.0 µg B/kg bw/d. Although the concentration of boron in some other food categories was higher (e.g., for baking ingredients and nut butters), the consumption levels for fruits and vegetables render them the highest contributor to dietary exposure.

These estimated dietary intakes in Canadians are similar to earlier estimates generated by Clarke and Gibson (1988) based on the analysis of boron in 1-day diet composites in 22 premenopausal women. The estimates are similar to, but slightly higher than, estimated dietary intakes in the United States based on the Continuing Survey of Food Intakes by Individuals, 1994-1996 (Rainey et al. 2002; IOM 2001), and intakes in the United Kingdom based on the 1994 UK Total Diet Study (Ysart et al. 1999). Fruits, beverages, vegetables and grains were the primary contributors to boron intake in the United States (Rainey et al. 2002).

**Table 9-1: Percentiles of usual dietary intakes ( $\mu\text{g B/kg bw/d}$ ) for boron for the general Canadian population from food and water<sup>3</sup>**

<b>Sex/ Age group</b>	<b>Median <math>\mu\text{g/kg bw/d}</math> (95% CI)*</b>	<b>95th percentile <math>\mu\text{g/kg bw/d}</math> (95% CI)*</b>
M/F: 6 mo. –1 yr.	50.9 (44.6, 63.0)	82.6 (68.7, 119.5)
M/F: 1–3 yrs.	91.7 (89.0, 94.8)	182.6 (173.3, 198.3)
M/F: 4–8 yrs.	63.6 (62.3, 65.2)	121.7 (116.2, 129.2)
M: 9–13 yrs.	37.8 (36.7, 39.1)	77.2 (72.9, 87.4)
F: 9–13 yrs.	36.2 (35.0, 37.5)	70.5 (65.9, 80.5)
M: 14–18 yrs.	26.2 (25.4, 27.1)	53.2 (49.8, 59.1)
F: 14–18 yrs.	25.4 (24.6, 26.2)	52.0 (48.5, 58.0)

<sup>3</sup> Most food items sampled and analyzed by the CFIA had high percentages of positive samples (80%), i.e., samples measured above the limit of quantitation. The samples with relatively few positives were generally meats and eggs. No values were imputed to non-detects; only positive samples were included in the exposure estimate presented in the deterministic estimates of exposure to boron in food. Some foods for which the CFIA had no data but that were reported in the ATSDR Toxicological Profile for Boron were included in the exposure estimates. Fish levels were not included in CFIA or ATSDR reports, but an entry was found in the EPA's Health Effects Support Document for Boron published in 2008 noting the median value for 10 fish samples. For each of the 500 iterations and each food cited in the Canadian Community Health Survey (CCHS) recall, boron concentration levels were randomly selected from the matching list of assayed values. Intakes were rolled up for each individual and each recall. The distribution of usual intakes for each dietary reference intake age-sex group and each distribution of intakes were calculated using the Software for Intake Distribution Estimation (SIDE) software created by Iowa State University's Department of Statistics and Center for Agricultural and Rural Development. Where possible, measured body weights were used; otherwise, self-reported body weights were used for intakes adjusted by body weight. For infants under two years of age, body weights from the United States National Health and Nutrition Examination Survey (NHANES) were used. The 0–6 month age group estimates were considered too unreliable to publish, in accordance with Statistics Canada requirements for publication of statistical analysis using CCHS consumption data. Body weights were measured or self-reported. Estimates were generated by the Food Directorate, Health Canada.

Sex/ Age group	Median µg/kg bw/d (95% CI) <sup>a</sup>	95th percentile µg/kg bw/d (95% CI) <sup>a</sup>
M: 19–30 yrs.	23.0 (22.1, 24.2)	45.0 (41.2, 53.5)
F: 19–30 yrs.	24.7 (23.8, 25.9)	48.6 (44.7, 54.6)
M: 31–50 yrs.	20.8 (20.0, 21.7)	43.3 (39.6, 51.1)
F: 31–50 yrs.	23.4 (22.6, 24.3)	51.2 (48.0, 59.7)
M: 51–70 yrs.	21.1 (20.5, 21.8)	43.7 (40.9, 49.0)
F: 51–70 yrs.	23.2 (22.5, 23.8)	47.4 (44.4, 52.8)
M: 71+ yrs.	20.4 (19.7, 21.4)	41.5 (38.8, 50.2)
F: 71+ yrs.	22.1 (21.4, 23.0)	45.1 (42.4, 52.4)

<sup>a</sup>95% confidence interval (lower, upper).

### *Intake estimates from environmental media, food and drinking water*

Average intake estimates from environmental media, food and drinking water were derived for the general Canadian population, based on concentrations of total boron measured in food, drinking water, air, soil and dust (presented in Appendix D). Based on these estimates, average daily intake of boron for the general public ranges from 3–92 µg B/kg bw/d, and, of these, naturally occurring boron in fruit, vegetables and to a lesser extent, drinking water is the primary source of total daily intake for the general public. Fruits and vegetables account for approximately 40–60% of dietary intake, while drinking water accounts for 3–16%. Air, soil and dust are negligible sources.

### **Products**

Based on a search of material safety data sheets (MSDSs), the U.S. Household Products Database, the GoodGuide, notifications under the *Cosmetic Regulations*, the Licenced Natural Health Products Database, and concentration data of boron in arts and crafts and toys, boric acid is found in thousands of products available to Canadians. Several targeted studies demonstrate an increase in blood boron concentrations following the use of products containing boric acid or precursors of boric acid (Wallace et al. 2002; Nielsen and Penland 1999; Hunt et al. 1997; Green and Ferrando 1994; Edwall et al. 1979).

The presense of boric acid in some products, including adhesives and sealants, arts and crafts materials, cleaning products, cosmetics, fertilizers, NHPs, paints and coatings, swimming pool and spa products, science education kits, textiles and toys (HPD 1993–; GoodGuide 2014; 2012 email from Consumer Product Safety Directorate, Health Canada to Existing Substances Risk Assessment Bureau, Health Canada [unreferenced]; 2013 email from Risk Management Bureau, Health Canada to Existing Substances Risk Assessment Bureau, Health Canada [unreferenced]; 2013 email from Food Directorate to Risk Management Bureau, Health Canada [unreferenced]; KEMI 2014), can result in direct exposure to Canadians during use. Other uses, including boron as a flame retardant in building materials, cellulose and fiberglass insulation, cotton mattresses, engineered wood and gypsum board (RPA 2008; Ball et al. 2012),

are more likely to result in indirect exposure to the general public, via household dust and indoor air as a result of use or presence of products in the home. Other uses, such as boron in glass and ceramics (CEH 2011), are considered to result in negligible exposure to boric acid.

Thousands of products on the market contain boric acid, and, therefore, for the purposes of this screening assessment, direct exposure to boric acid was quantified for five product categories that were considered to have a significant contribution to exposure and/or were frequently used. These categories include arts and crafts materials and toys, cleaning products, cosmetics, NHPs, and swimming pool and spa products. For each category, sentinel products were selected to characterize exposure potential for the general public; sentinel product intake estimates, by category, are presented in the following subsection.

#### *Arts and crafts materials and toys*

Boric acid can be a component of many arts and crafts materials. The U.S. Art and Crafting Materials Institute (ACMI) measured soluble boron (using ASTM standard D5517) in marker inks (range 8.3–1400 ppm), technical drawing inks (1400 ppm), ceramic glazes (67–40 000 ppm), pencils (27–650 ppm), coloured sand (525 ppm), paints and enamels including acrylic, gouache, watercolour, water colours and oils (13–8300 ppm), colours and pigments including encaustic and acrylic (1600–17 400 ppm), and glue (380–1800 ppm) (Stopford 2013). Many of these products, such as marker inks, ceramic glazes, pencils and glue, are marketed to children or to teachers for use by children.

Boric acid can also be a component of some commercially-made toys. Soluble boron has been quantified in plastic putty, modelling clay and modelling dough by the ACMI, ranging from 225–1300 ppm (Stopford 2013). In Canada, boric acid and salts of boric acid are specifically prohibited in toys under section 22 of the *Toys Regulations* of the *Canada Consumer Product Safety Act* (Canada 2010, 2011). Health Canada conducts periodic sampling and testing to verify compliance with its regulations, by targeting products that may be more likely to not meet health and safety requirements due to characteristics that are observed. Health Canada compliance testing conducted from 2002–2009 found measurable boric acid in play dough, glue and paint samples. In 2002, 85% of the clay, modelling dough, putty and glue samples analyzed had detectable boric acid concentrations, ranging from < 4 ppm–49 000 ppm (Health Canada 2002). Boric acid was also detected in science kits. In 2004 and 2009, boric acid was detected in clay and plasticine at concentrations of 27–40 300 ppm (Health Canada 2004, 2009b, 2009c). For commercially available children's toys, compliance and enforcement of the existing prohibition on boron will continue as a part of the regular enforcement of the *Toys Regulations* under the *Canada Consumer Product Safety Act*.

Borax is a precursor of boric acid and is a common ingredient in make-your-own crafts and toys, including crystal formations, slime and play dough (The Dial Corporation

2014). Online sources provide recipes and ideas for making these crafts at home, school, birthday parties or science fairs (American Chemical Society 2014; PBS 2014; About Education 2014; Government of Canada 2014). Borax is available to consumers in grocery and hardware stores in Canada. When making crafts or toys, powdered borax is typically mixed in a bowl by hand with glue or water.

To evaluate potential exposure to adults and children using arts and craft materials and playing with toys containing boric acid, a sentinel scenario was generated. Exposure during children's use of homemade modelling clay was selected as a potentially high-exposure scenario. When playing with modelling clays or slimes, there is potential for oral and dermal exposure from the ingestion of small quantities of the material, via incidental hand-to-mouth activities or intentional consumption. Dermal intake estimates for a child playing with 350 g of homemade modelling clay ranged from 69–1381 µg/kg bw/event. Oral intake for a child from ingestion of 100 mg–5 g of modelling clay was 56–2819 µg/kg bw/event. Estimated intakes of boric acid from the use of arts, crafts and toys are presented in Appendix E.

### *Cleaning products*

Boric acid may be found in a variety of cleaning products. Based on a search of MSDSs, the U.S. Household Products Database and GoodGuide, boric acid was found in over 200 cleaning products and borax was found as an ingredient in 244 household cleaning products, including air fresheners, all-purpose cleaners, bleach products, fabric treatments, glass and surface cleaners, household chemicals, household cleaners, kitchen cleaners, laundry products, laundry detergents and stain removers (HPD 1993–; GoodGuide 2014). The cleaning products generally fall into five main categories: all-purpose cleaners; dishwashing detergents; floor, carpet and furniture cleaning products; laundry detergents; and toilet bowl cleaners. Some products, such as some laundry detergents, are marketed as baby products. Overall, the concentration of boron found in products was highly variable, ranging from 0.01–11% (this includes products containing 100% borax). The products occur in a variety of formulation types, including powders, solid tablets, pastes, putties, liquids and aerosols, and are either ready-to-use or require dilution in water.

Exposures can occur during mixing, loading or applying of cleaning products. Application methods can vary depending on the formulation type and the use pattern, and therefore a single product can have a wide variety of potential exposure scenarios. For example, powdered borax can be applied directly to hard surfaces as an abrasive cleaner, diluted in water to clean hard surfaces (such as floors, countertops, furniture), diluted in water to steam-clean carpets, added as a powder to automatic dishwashers or washing machines, or added to water for hand-washing of laundry or dishes. There is also potential for post-application exposure to residues following the use of cleaning products, including exposure to residues on dishes, clothing, floors and furniture. Given the variation in types of cleaning products, concentrations of boron, formulation types and application methods, there are numerous potential exposure scenarios.

To evaluate potential exposure to people from the use of cleaning products, several sentinel scenarios were developed: ready-to-use spray cleaner, dishwashing detergent, floor cleaners, and hand-washing laundry with detergent. These products and scenarios were considered to represent high-exposure scenarios or have the potential for frequent use. Application of a ready-to-use general purpose cleaner (0.7% boron) on hard surfaces results in dermal exposure estimates ranging from 10–199 µg B/kg bw/d. Hand-washing dishes with a product containing 0.14% boron results in dermal exposure estimates from 4–86 µg B/kg bw/d; loading automatic dishwashers would result in lower exposure for the user. Hand-washing a floor with a ready-to-use floor cleaning product containing 1.75% boron could result in dermal estimates ranging from 27–542 µg B/kg bw/d and post-application dermal exposure to a toddler crawling on the floor of 8–160 µg B/kg bw/d and another 120 µg B/kg bw/d from oral hand-to-mouth exposure. Loading powdered laundry products containing 11.4% boron was estimated to result in 0.02 µg B/kg bw/d via the inhalation route of exposure. Estimated intakes of boric acid from the use of cleaning products are presented in Appendix E.

Some cleaning products are formulated as tablets (e.g., laundry and dishwashing detergents), which mitigates exposure to the user during loading and application. However, these types of formulations present a reasonably foreseeable accidental exposure to boric acid for young children through mouthing or ingestion.

### *Cosmetics*

Boric acid<sup>4</sup> is an ingredient in approximately 1100 cosmetics notified to Health Canada under the *Cosmetic Regulations* (2015, email from the Consumer Product Safety Directorate, Health Canada, to the Existing Substances Risk Assessment Bureau, Health Canada; unreferenced). Boric acid is an ingredient in anti-wrinkle preparations, baby products, barrier creams, bath preparations, body make-up, deodorant, douches, eye lotions, eye make-up, face make-up, fragrances, genital lubricants, hair bleaches, hair conditioners, hair dyes, hair grooming products, hair shampoo, hair straighteners, hair waving preparations, massage oils, mouthwash, shaving preparation, skin cleansers, skin moisturizers, and tanning preparations. Of all cosmetic product types, boric acid is most commonly found in skin moisturizers and skin cleansers.

Borax was identified as an ingredient in approximately 400 cosmetics in the GoodGuide, which is a resource for information on consumer products in the United States (GoodGuide 2014).

To evaluate potential exposure to users of cosmetics, daily intake estimates were generated for products with the potential for dermal, oral and mucosal exposure. Body

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<sup>4</sup> Boron nitride is a common ingredient in cosmetics but is not considered a precursor to boric acid, and therefore is not included in this assessment.

creams, body soaps and diaper creams were selected as sentinel products to represent potential intake of boric acid from the use of dermally applied cosmetics. Mouthwash, lipstick and genital lubricants were selected to represent orally and mucosally applied cosmetics. These products were selected as sentinels as they are considered to result in high exposure relative to other cosmetics and have the potential for daily or frequent exposure. In the 1950s, cases of infant poisoning were reported from the use of products containing boric acid used to treat damaged skin from diaper rash (MacGillivray and Fraser 1953; Fisher et al. 1958). These reports demonstrate the potential for systemic exposure to boric acid following use on abraded skin. The GoodGuide identifies borax (a precursor to boric acid) as an ingredient in 15 baby care products sold in the United States, including diaper creams, and therefore diaper creams were evaluated as a sentinel product given that they may be used on broken or abraded skin.

Daily intake estimates were generated using the maximum permissible concentrations (this value reflects the maximum concentration of 5% boric acid, equivalent to 0.87% boron, outlined in the Hotlist restriction) and frequency of use per day data. When relevant, dermal absorption estimates of 0.5 and 10% were incorporated for non-abraded skin, whereas absorption across broken or abraded skin and mucosal membranes was considered to be 100%. Although the Hotlist entry for boric acid describes a maximum limit of 5%, there are cosmetic products available to Canadians (such as powdered hand soaps) that contain 60–100% borax, equivalent to up to 65% boric acid (The Dial Corporation 2013; GoodGuide 2014; HPD 1993). It should be noted that current market data indicates that concentrations of boric acid in diaper creams, and other cosmetic baby products, sold in Canada are much lower than the level of 5% (i.e., less than 0.1%) (2015 email from the Consumer Product Safety Directorate, Health Canada, to the Risk Management Bureau, Safe Environments Directorate, Health Canada; unreferenced).

Intake estimates for body lotions, skin cleansers and diaper creams are estimated to range from 0.03–1399 µg B/kg bw/d. Intake estimates for mouthwash, lipstick and genital lubricants range from 2–740 µg B/kg bw/d. Estimated intakes of boric acid from the use of cosmetics are presented in Appendix E.

### *Natural health products*

Boron<sup>5</sup> is present in over 700 licensed NHPs in Canada, both as a medicinal and non-medicinal ingredient (LNHPD 2014). Most commonly, boron is used as a medicinal ingredient in multi-vitamin/mineral supplements (intended for adult use up to a

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<sup>5</sup> Source materials for boron are presented in Section 5 and are considered precursors of boric acid. Boron nitride is a common non-medicinal ingredient in NHPs but is not considered a precursor to boric acid and therefore is not included in this assessment.

maximum daily dose of 700 µg B/d), and to a lesser extent in multiple-ingredient joint health products (up to a maximum of 3360 µg B/d [Health Canada 2007a, 2007b, 2014b]). Boron is present in a smaller number of licenced products for oral (in addition to the ones mentioned above), dermal, ophthalmic and vaginal use, including homeopathic medicines, oral antiseptic rinses, toothpaste, ointments and skin lotions, sunscreens, yeast infections, eye drops and eye washes (LNHPD 2014).

To evaluate potential exposure to users of NHPs, daily intake estimates were generated for users of multi-vitamin/mineral supplements and multiple-ingredient joint health products, which were selected as sentinel products because they result in high exposure and are used daily. Numerous studies document an increase in boron blood concentrations following the use of oral supplements containing boron (Wallace et al. 2002; Hunt et al. 1997; Nielsen and Penland 1999).

Intake estimates for adults consuming multi-vitamin/mineral supplements and multiple-ingredient joint health products, based on the maximum permitted concentrations, are 10 and 47 µg B/kg bw/d, respectively. Estimated intakes of boric acid from the use of NHPs are presented in Appendix E.

#### *Swimming pool and spa products*

Swimming pool and spa products may contain boric acid. As pesticides, algacide and sanitizer pool products containing boron, present as a formulant, are regulated under the *Pest Control Products Act* (Canada 2002). However, other swimming pool and spa products which are not pesticides, including performance products and water conditioners available to Canadians, may contain boron. Target concentrations of 30–50 ppm B are frequently recommended to make water feel soft, improve water clarity and make water easier to maintain (Nisus Corporation 2010; Haviland Consumer Products, Inc. 2007). To evaluate potential exposure to people swimming in pools or using spas containing boron, total intake estimates (combined oral and dermal) were derived for all age groups (infants through to adults) swimming in pools. Estimates were based on algorithms from the U.S. EPA (2003) SWIMODEL using a maximum dermal  $K_p$  of  $5.0 \times 10^{-4}$  cm/h (Wester et al. 1998b) and the recommended concentration of boron in pool water of 50 ppm. Combined (oral and dermal) exposure estimates from swimming ranged from 36–518 µg B/kg bw/event (Appendix E). Oral intake accounted for the majority of intake.

### **Biomonitoring**

Boron has been measured in a wide variety of human tissues, including whole blood, serum, plasma, red blood cells, platelets, urine, breast milk, hair, nails, semen, placenta, and cord blood. Studies examining worker exposure to boron have demonstrated that serum, whole blood, urine and semen are all good biomarkers of boron exposure and are all highly correlated with total daily boron intake (Xing et al. 2008; Robbins et al. 2010; Duydu et al. 2011). In a study conducted in Turkey, whole blood boron concentrations were considered much more reliable indicators of

boron exposure (and were used to reclassify exposed and unexposed participants) than the initial classification based on estimates of intake from environmental media (Duydu et al. 2011). Blood boron (serum, plasma, whole blood) concentrations have been used as an indicator of boron status and excessive boron intake in numerous supplementation studies, and blood is considered a relatively reliable biomarker of exposure related to potential health effects (Nielsen 2009). Whole blood boron concentrations are slightly higher than serum because low concentrations of boron are found in red blood cells and platelets. Based on these reasons, blood boron concentrations were evaluated as a method of quantifying boron exposure in the Canadian population. Blood boron concentrations in humans are presented in Appendix F.

Although boron has not been included in large-scale biomonitoring initiatives such as the Canadian Health Measures Survey or National Health and Nutrition Examination Survey, blood boron concentrations have been measured in several smaller population studies, studies on trace-element analysis, supplementation studies, and occupational exposure studies. The most comprehensive dataset on blood boron concentrations in Canadians originates from the Alberta biomonitoring program. Blood boron was measured in pooled serum samples from over 50 599 pregnant women and 1373 children (Alberta Health and Wellness 2008; Government of Alberta 2010). Serum samples were pooled into 158 pools stratified by age, geographical location, and season. Average blood boron concentrations ranged from 13–34 µg/L in pregnant women and 29–33 µg/L in children (Alberta Health and Wellness 2008; Government of Alberta 2010). Blood samples from different subjects were pooled prior to laboratory analysis, and therefore the variability between individuals was lost. These pooled data provide reliable estimates of average population-level exposure in pregnant women and children, but do not provide information on the overall distributions of exposure, most importantly the upper end of the exposure distribution. The only other blood boron concentration data in Canadians originate from studies conducted by Clarke and colleagues (1987a, 1987b, 2004), in which average concentrations in 12 individuals were measured at  $30.8 \pm 5.6$  µg/L with a range of 15.3–79.5 µg/L. Other population-level studies conducted in the United States and Europe reported average blood boron concentrations similar to those found in the Alberta data and Clarke et al. (1987a), ranging from 11–56.7 µg/L, with the exception of France where the average blood boron concentration in a study of 180 males was much higher at 126 µg/L (Ferrando et al. 1993; Pahl et al. 2001; Abou-Shakra et al. 1989; Rodushkin et al. 1999; Vanhoe et al. 1993; Heitland and Köster 2006; Yazbeck et al. 2005; Gouille et al. 2005; Hasbachecei et al. 2013). Maximum values of 170.4 and 195 µg/L, respectively, were reported from studies in the United Kingdom (n=50) and northern Germany (n=130) (Abou-Shakra et al. 1989; Heitland and Köster 2006). Given that there are limited data on the upper tails of the exposure distribution (e.g., maximum, 95<sup>th</sup> percentiles) in Canadians, the maximum data from the United Kingdom and Germany (170.4 and 195 µg/L) and the average concentration from France (126 µg/L) will be considered as surrogate data to represent the upper tail of the exposure distribution for Canadians.

Age and sex trends have been observed in the overall dataset. In a study of mother-infant pairs in northern Argentina and Chile, boron was found to transfer from the mother to the developing fetus via the placenta, and later via breast milk (transfer was greater via the placenta) (Harari et al. 2012). In Alberta, average blood boron concentrations were significantly higher in children under age 13 than in pregnant women. There are no blood concentration data for children under age 2, so it is unknown if blood concentrations would be higher or lower in this age group. In adults, an increase in blood boron concentrations with age was observed in studies conducted in Alberta, Turkey and Japan (Alberta Health and Wellness 2008; Hasbachecei et al. 2013; Usuda et al. 1997). In the same Japanese study, blood boron concentrations increased in adult males from 20 to 49 years, followed by a plateau, followed by a second increase at age 70; in females there was a continuous steady rise in blood boron concentrations from age 20 onward; and, overall, blood boron concentrations were significantly higher in males than females.

Boron concentrations vary in different biological media. For example, boron was found at much higher concentrations in semen than blood in a series of worker exposure studies in China (Robbins et al. 2010; Scialli et al. 2010; Xing et al. 2008).

Blood boron concentrations can also vary by geographical location, which in some cases can be explained by variations in the boron concentrations in environmental media and in diet. Blood boron concentrations are markedly higher in populations living in northern Argentina and Chile than other parts of the world, with averages ranging from 22–901 µg/L, resulting from high boron content in the soil and drinking water (Barr et al. 1993, 1996; Harari et al. 2012). Blood boron concentrations as high as 2000 µg/L have been reported in Chileans in this region (Barr et al. 1996). Elevated blood boron concentrations in a Japanese population, with a geometric means of 79.8 and 67.9 µg/L for males and females, respectively, were attributed to differences in dietary intake—including the consumption of green tea, which has a high boron content (Usuda et al. 1997). In Canada, blood boron concentrations were higher in women from southern Alberta than central and northern Alberta (Alberta Health and Wellness 2008); the reasons for this are unknown.

Several targeted studies demonstrate an increase in blood boron concentrations following the use of products containing boric acid or precursors to boric acid (Wallace et al. 2002; Nielsen and Penland 1999; Hunt et al. 1997; Green and Ferrando 1994; Edwall et al. 1979). For example, supplement use can result in significant increases in blood boron concentrations. Multiple studies conducted in the general population, peri- and post-menopausal women, and weightlifters examined blood boron concentrations before and after supplement use. In one study, baseline blood concentrations averaging 14 µg/L peaked at 136 µg/L 4 hours after ingestion of an 11.6 mg boron dose. At 6 hours, blood concentrations were still elevated at 124 µg/L (Wallace et al. 2002). Three other studies found 1.5–1.7-fold increases in plasma boron concentrations following 2.5 and 3 mg doses from supplements (Hunt et al. 1997; Nielsen and Penland 1999; Green and Ferrando 1994). The use of other products containing boron can also result in elevated blood boron concentrations. In one study, blood boron increased four-

fold following use of a mouthwash and remained elevated over the baseline for 24 hours after use (Edwall et al. 1979). In addition, there was a low rate of accumulation of blood boron following repeated use of the mouthwash over a one-week period.

### **Exposure summary**

Blood boron concentration data are available to characterize exposure to Canadians from studies conducted in Canada, the United States and Europe. Total boron measured in blood in individuals provides a measure of integrated exposure for individuals, from all routes (oral, dermal and inhalation) and all sources (including environmental media, diet, and frequent or daily use products to which they were exposed). Males have higher concentrations of boron in blood than females. For adults, there is a steady increase in the concentration of boron in blood with age; despite this trend in adults, blood boron concentrations are higher overall in children.

The Alberta Biomonitoring Program (Alberta Health and Wellness 2008; Government of Alberta 2010) provides average estimates of exposure from over 50 000 pregnant women and over 1000 children, both of which are populations of concern for the identified health effects of boric acid. Average blood boron concentrations from the Alberta biomonitoring studies (34 µg/L) are considered adequate to represent average concentrations in Canadians and are representative of exposures in children and adults (Alberta Health and Wellness 2008; Government of Alberta 2010). Given that there are no adequate Canadian data to characterize upper-percentile blood boron concentrations, the maximum values from the United Kingdom and Germany (170.4 and 195 µg/L, respectively) as well as the average concentration from France (126 µg/L) support the use of 195 µg/L to represent the upper tail (e.g., 95<sup>th</sup> percentile) of the exposure distribution for the general Canadian public (Yazbeck et al. 2005; Abou-Shakra et al. 1989; Heitland and Köster 2006). Biomonitoring data are often considered the “gold standard” in exposure assessment, and, in this case, sufficient high-quality biomonitoring data exist to adequately characterize exposure to the Canadian population, including sub-populations of interest (e.g., children and pregnant women). These blood boron concentrations will be carried forward to risk characterization in order to represent exposure to Canadians.

Although the whole blood biomonitoring data provide a measure of integrated exposure from all routes and sources for the general population, including food, drinking water, dust, soil and products containing boron, not all products available to Canadians or every potential exposure source are captured in these studies. In addition, biomonitoring data are unable to identify sources of exposure. Accordingly, average intake estimates were derived for the general Canadian population in order to identify the main sources of intake.

Based on exposure modelling intake estimates, food, drinking water and products were determined to be primary contributors to total daily intake, whereas soil, dust and air were minor contributors. Fruits, vegetables, in particular, are important sources of dietary intake. Representative, high-quality Canadian data were available to

characterize exposure to boron in air, soil, dust, food and drinking water, resulting in high confidence intake estimates. Average daily intakes from environmental media, food and drinking water ranged from 3–92 µg B/kg bw/d.

Based on modelling intake estimates for products containing boric acid (and precursors), products may be significant contributors to total daily intake. Systemic exposure was estimated for users of products containing boric acid, including arts and crafts, toys, cleaning products, cosmetics, NHPs, and swimming pool and spa products. Intakes for sentinel products were estimated to range from 0.03–2819 µg B/kg bw/d. Intake estimates from some products greatly exceed average daily intake from environmental media, food and drinking water. However, overall confidence in the intake estimates from products is low to moderate, due to uncertainties in adequate algorithms for estimating intake, selection of sentinel products, dermal absorption and the lack of information on directions for use of specific products, frequency of use and concentration.

### **Relationship of blood boron to boron intakes**

Several human studies have identified blood boron concentration as an indicator of boron intakes (Neilsen and Penland 1999; Neilsen 2009; Hunt 1997; WHO 1998). A regression correlation between boron oral intakes and blood (whole blood, plasma, serum) boron concentrations was derived by Health Canada to facilitate the estimation of intake from available blood boron data obtained from biomonitoring studies. Details of the regression approach are described below.

Toxicokinetic data indicate that the blood boron concentrations reach steady-state levels effectively post-exposure (Treinen and Chapin 1991). Absorbed boron is distributed rapidly and evenly throughout the body's soft tissues, with slight accumulation in bone (2–3 times higher). A three-compartment model used to describe blood and urine concentration of boric acid following oral and intravenous exposure in male volunteers suggests that additional compartments were needed to describe the initial rapid elimination of boron following intake and a gradual release after three days of intake (Jansen et al. 1984a, 1984b). This model may also suggest that accumulation of boron depends on the rate to deplete body stores and the renal clearance. A non-linear relationship between boron intake and blood concentrations was suggested by Dourson et al. (1998) after reviewing human and rat studies. When additional new data were applied to this original observed function, the consistency for mean blood boron concentrations and exposure doses was within the expected variability. As a result, a power function adjusted from the Dourson et al. (1998) original observation was used to describe the correlation between the mean blood boron concentrations and daily boron intake in humans in this assessment.

Studies on boron exposure (i.e., dietary, supplements or drinking water) were selected when deriving the regression correlation, because those sources of exposure are more relevant for the general population (see Appendix G). In dietary supplementation studies, individuals were supplemented with known concentrations of boron, and blood

boron concentrations were monitored at regular intervals (Nielsen and Penland 1999; Hunt et al. 1997; Green and Ferrando 1994; Wallace et al. 2002). Intake estimates from supplementation studies include boron exposure from both supplements and diets. Because boron is well absorbed and is excreted in urine, Neilson and Penland (1999) estimated boron intakes based on urinary boron excretion. In Hunt et al. (1997), the blood boron concentration was presented as  $\mu\text{moles per litre}$ , with the molecular weight of 10.8 g/mol applied to calculate blood boron concentration in  $\mu\text{g/L}$ . In Green and Ferrando (1994), the average plasma boron concentrations were calculated based on the individual plasma data. For individuals with plasma boron concentrations below or equal to limits of detection, half of the limit was assumed.

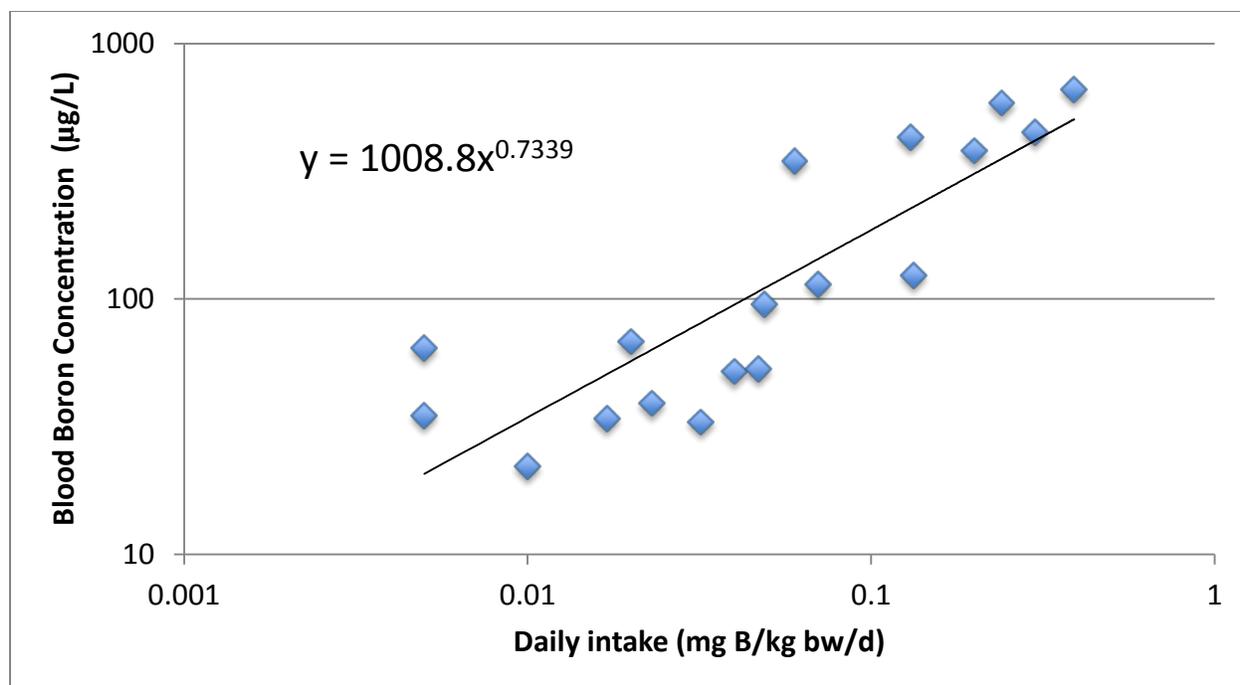
In drinking water studies, blood boron concentrations were monitored in people living in northern Chile, an area with naturally high concentrations of boron in drinking water and soil (Appendix G) (Barr et al. 1993; Harari et al. 2012). Barr et al. (1993) calculated the daily intake of boron based on the boron concentrations in drinking water; the dietary intakes were not considered. Harari et al. (2012) did not estimate the boron intakes, and only provided the boron concentration in drinking water. An average water consumption rate of 1.8 L per day was assumed when estimating boron intakes, a rate consistent with the value assumed in Barr et al. (1993). Similar to Barr et al (1993), Harari et al. (2012) did not include a dietary component in deriving intake estimates.

Workplace exposure to boron arises primarily from dust, and assumptions on particle size, pulmonary disposition and bioavailability may bias the exposure estimates under occupational settings compared with the general population. Therefore, only the control groups (local community controls and remote background controls) from occupational studies were included in the regression correlation. The community controls were individuals from the same community as boron workers, but without workplace boron exposure, while the remote-area background controls were individuals from another community where background boron exposure levels were low. As indicated in Appendix G, all oral intakes were converted to mg B/kg bw/d. When the body weights were not provided in the study, an average body weight of 70 kg was applied for all cohorts, except for Chinese cohorts. In general, body weights of Chinese people are lower than the other ethnic groups, and therefore an average body weight of 60 kg was applied. When the blood boron concentrations were presented in a weight/weight (wt/wt) basis, the blood density was assumed as 1 g/mL to convert blood boron concentrations from wt/wt to weight/volume (wt/v).

Based on the regression analysis, the mathematical correlation between blood boron concentrations and the oral intakes of boron is shown in Figure 9-1, and can be explained as follows:

$$\text{Blood concentration } (\mu\text{g/L}) = 1008.8 (\text{daily intake})^{0.7339}$$

where daily intake is in mg B/kg bw/d.



**Figure 9-1: Blood boron concentrations as a function of daily intakes based on several exposure studies**

### 9.3 Characterization of risk to human health

Results from animal experiments demonstrate that boric acid adversely affects fertility, reproduction and development. These effects observed across species were very similar, both in nature and effective doses. The lowest point of departure in the animal database was a BMDL of 2.90 mg B/kg bw/d for decreased testicular weight, derived from dog studies (which have limitations in quality). The other notable point of departure is an NOAEL of 9.6 mg B/kg bw/d identified in rats, based on fetal toxicity in the absence of maternal toxicity. Given that the dog is a more sensitive animal model, and because the rat developmental toxicity study was limited to a 20-day *in utero* exposure with limited examinations of fetal or maternal toxicity, there are limitations with the use of this endpoint for risk characterization as well. Given the limitations in the available animal database, margins of exposure were derived from the BMDL of 2.90 mg B/kg bw/d as per the PMRA (Health Canada 2012).

Given that no additional animal studies have been conducted since the publication of the PMRA risk assessment (Health Canada 2012), epidemiological data were assessed to determine if adequate studies were available to derive points of departure for risk characterization. It was concluded that the epidemiological studies in humans are collectively insufficient to demonstrate the absence of an adverse effect of boron exposure in humans, due to several limitations in design. The Committee for Risk Assessment of the ECHA (ECHA 2014) concluded that the toxicity data from four species (dog, rat, mice and rabbit) provide clear evidence of adverse effects on sexual

function, fertility and development. The methodological limitations in human studies limit their utility, but do not contradict the animal data (ECHA 2014). As such, effects observed in animals are considered relevant to humans and are used for the risk assessment.

Canadians are exposed to naturally occurring and anthropogenic boric acid from environmental media, food, drinking water and products. Intake estimates indicate that naturally occurring boron in fruits, vegetables and, to a lesser extent, drinking water are primary sources of exposure. Estimates of intakes from uses of boric acid in some arts, crafts, toys, cleaning products, cosmetics, NHPs and swimming pool and spa products indicate that these may be significant sources of exposure to the general population.

With the availability of biomonitoring data, exposure to boric acid was characterized using predicted daily intakes based on the measurement of total boron concentrations in the blood of Canadians and Europeans. Total boron blood concentrations are a measure of integrated exposure to all precursors of boric acid, from all routes (oral, dermal and inhalation), and all sources (including environmental media, food, and daily- or frequent-use products). Average and upper percentile (e.g., 95<sup>th</sup>) blood boron concentrations for Canadians are considered to be 34–195 µg/L based on measured data from the Alberta biomonitoring program and European data. Using the relationship between blood boron concentrations and intake estimates, as described in section 9.2.2, where blood concentration (µg/L) = 1008.8 (daily intake in mg/kg bw/d)<sup>0.7339</sup>, average and upper-percentile blood concentrations of 34 and 195 µg/L correspond to intakes of 10 and 107 µg B/kg bw/d, respectively.

Risk to human health for boric acid was characterized based on a comparison of predicted intake estimates based on blood boron concentrations to the critical health effect. The margins of exposure between average and upper percentile intakes derived from average and upper percentile biomonitoring data and the critical effect (2.90 mg B/kg bw/d) are 290 and 27 respectively. These margins of exposure are considered potentially inadequate to address uncertainties in the exposure and health effects databases.

#### **9.4 Uncertainties in the characterization of risk to human health**

The human health effects database does not measure the same range of toxicological endpoints noted in the animal database, reducing the ability to make species-sensitivity comparisons. Although cardiovascular and endocrine effects were noted in several human supplement studies, there is inadequate information available to accurately characterize the risks of these possible health effects.

The animal database mainly consists of older studies with inherent limitations. Administered doses in animal studies have a degree of uncertainty, because the background boron concentration in animal feed and/or stability and homogeneity analyses of administered doses were not conducted for many studies in the animal database. The dog studies have been criticized for lack of good laboratory practice (the

studies were conducted prior to Good Laboratory Practice implementation), and there is some concern regarding the dose relationship with regards to testicular atrophy due to the animals' age. For a fulsome discussion of the limitations of this study see (Austria 2008a). Given that the rat study is only conducted over a 20 day dosing regime, has limited examinations not limited to fetal development, and does not examine the most sensitive organ at the most sensitive life stage identified in the dog studies, there is uncertainty about extrapolation of this study to assess developing male reproductive function. Several endpoints of potential concern reported in humans (cardiovascular, endocrine, cancer and testicular toxicity) are not fully characterized in the animal database, and therefore there is uncertainty about adequacy of the database to fully characterize health effects associated with boric acid. Conducting toxicity studies to fully address these concerns could reduce database uncertainty and allow for refinement of the risk characterization.

It remains unclear to what extent boron bioavailability could be reduced by the natural boron complexes that form in plant materials, and any matrix effects that occur as a result. The current screening assessment does not specify a target margin of exposure (MOE), or chronic reference dose. Rather, the assessment presents the achieved margins of exposure to the proposed point of departure (POD) for testicular toxicity (BMDL based on combined data from two 90-day dog studies). The screening assessment refers to the Health Canada pesticide re-evaluation under the *Pest Control Products Act* (PCPA) (Health Canada 2012), which identified, for boron, a target MOE of 300 to the POD. It is acknowledged that other organizations have derived lower target MOEs based on the publically available boron database, and then applying various adjustment factors to the standard uncertainty factors. Of note, target MOEs between 25 and 60 were applied to the POD of 9.6 mg B/kg bw/d from the rat developmental toxicity study (EFSA 2013; EGVM 2003; IOM 2001; WHO 1998), mainly through a refinement constructed on human pharmacokinetic variability factors. For example, by subdividing the intraspecies default UF of 10 into 3.2 for toxicokinetics and 3.2 for toxicodynamics, and using the glomerular filtration rate data in pregnant women as also reported by Dourson et al. (1998), EFSA (2013) and EGVM (2003) adjusted the toxicokinetic subfactor to 1.8, resulting in a chemical-specific intraspecies UF of 6 ( $3.2 \times 1.8 = 5.72$ ) and an overall UF of 60. WHO (1998), also by subdividing the UF into toxicokinetics and toxicodynamics, reduced the default interspecies UF of 10 based on half-life similarities in the elimination of boron between rats and humans; however, clearance has been reported as being more important than half-life for comparison of toxicant elimination (Zhao et al. 1999). Another recent article from Dourson and collaborators (Hasegawa et al., 2013) proposes 0.13 mg B/kg bw/d as the most appropriate cRfD boron, applying an UF of 78 to a rat developmental POD of 10.3 mg B/kg bw/d.

The pesticide assessment (Health Canada 2012) did not agree with refining the intraspecies factor, given the inadequacy and large variability in the human data on which these refinements were based (Health Canada 2012). Additional human data/information examined during the current assessment further indicating the large degree of human variability supports the Health Canada 2012 interpretation of the

human pharmacokinetic data. Thus, while there remains uncertainty as to the most appropriate level of conservatism required for the screening assessment, it is important to note that the proposed conclusion of this screening assessment would remain the same with the use of any one of the target MOEs suggested by other regulatory bodies.

There is uncertainty about whether homeostatic capacity may be exceeded by environmental media exposure levels. However, in the absence of definitive studies, the risk characterization for boron focused on total exposure based on biomonitoring data.

Boron is not included in the Canadian Health Measures Survey or National Health and Nutrition Examination Survey, which provide robust population-level exposure estimates (> 5000 participants per cycle, data from two or more cycles could be combined for analysis). The Alberta biomonitoring data include > 50 000 pregnant women and > 1300 children, but due to the study design (pooled serum), there are no data to describe exposure in the upper tails (95th percentile) of the distribution. In addition, in other studies men have been found to have higher exposure and are not included in the Alberta study. Data from the United States and Europe were evaluated to enable the evaluation of risks in individuals with the highest exposures, but differences in study design (e.g., pooled serum vs. individual samples, e.g., target population [general population studies vs. supplement vs. occupational]) and analytical methods (colorimetric vs. neutron activation analysis mass spectrometry [NAA-MS] vs. inductively coupled plasma mass spectrometry [ICP-MS]) made comparisons between studies difficult. It is uncertain to what degree the European biomonitoring data are representative of Canadian exposure to boron, although average concentrations are similar, increasing confidence in the use of this data for Canadians. It is possible that the upper percentile (e.g., 95th) blood concentrations in Canadians were not captured in the European datasets, and the extent to which exposure from products is captured in the biomonitoring data is uncertain. The inclusion of boron in a national population-level biomonitoring study (e.g., the Canadian Health Measures Survey), and targeted studies on users of products containing boric acid or precursors of boric acid, would reduce uncertainty in the exposure characterization.

There is uncertainty associated with the intake estimates for users of products containing boric acid, due to a lack of data on product use (e.g., frequency, amount of product used, market share and target market), of adequate exposure models to predict intake from product use, and of targeted exposure studies. There is uncertainty regarding the characterization of dermal absorption, because the available studies have several limitations, including poor mass balance and only one route of elimination measured. Additional data, such as dermal absorption (e.g., OECD test guideline for in vitro human and rat, and in vivo rat) and targeted exposure studies, would reduce uncertainty in the exposure assessment.

There is moderate to high confidence in the regression correlation developed between daily intake of boron and steady-state blood boron concentration, as presented in subsection 9.2.2. A similar analysis of blood boron concentrations as a function of

administered dose has been conducted by Dourson et al. (1998), and the relationship between blood boron concentrations and exposure doses was previously used to characterize risk of boron exposure (Bolt et al. 2012). This current evaluation expands upon earlier work by Dourson et al. (1998) to include additional human studies with exposure sources relevant to the general Canadian population (e.g., dietary supplement studies and control groups from occupational studies). Given that the current correlation is derived from relevant intake data, exposure sources were considered relevant to the general Canadian population.

## **10. Conclusion**

Considering all available lines of evidence presented in this draft screening assessment, there is risk of harm to organisms, but not to the broader integrity of the environment, from boric acid, its salts and its precursors. It is proposed to conclude that boric acid, its salts and its precursors meet the criteria under paragraph 64(a) of CEPA, as they are entering or may enter the environment in a quantity or concentration or under conditions that have or may have an immediate or long-term harmful effect on the environment or its biological diversity. However, it is proposed to conclude that boric acid, its salts and its precursors do not meet the criteria under paragraph 64(b) of CEPA, as they are not entering the environment in a quantity or concentration or under conditions that constitute or may constitute a danger to the environment on which life depends.

Based on margins of exposure between adverse health effects and intake estimates considered inadequate to address uncertainties in the exposure and health effects database, it is proposed to conclude that boric acid, its salts and its precursors meet the criteria under paragraph 64(c) of CEPA, as they are entering or may enter the environment in a quantity or concentration or under conditions that constitute or may constitute a danger in Canada to human life or health.

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## Appendices

### Appendix A: Lists of Boron-containing Substances that are Precursors or Non-precursors of Boric Acid

Fourteen substances were identified as priorities for further action during categorization. Given that the screening assessment focuses on a common moiety of concern (boric acid), all boron-containing substances on the *Domestic Substances List* (DSL) (and associated hydrated forms that do not appear on the DSL), other than polymers, were subsequently evaluated for their potential to be precursors of boric acid (Environment Canada and Health Canada 2014). Substances determined to be precursors are listed in Table A-1, and those found to be non-precursors are listed in Table A-2. Additional substances were identified as potential contributors to boric acid in the environment (e.g., hydrated forms of substances on the DSL, which are not listed on the DSL because they are considered mixtures; boron-containing substances on other Canadian inventories; or other substances in commerce in Canada that may be boric acid precursors) and are included in the lists below and further discussed in Environment Canada and Health Canada (2014). Most of these additional substances of interest are captured within Harmonized System (HS) codes for which import data were requested of the Canada Border Services Agency (CBSA).

**Table A-1: Boric acid, its salts and its precursors**

CAS RN	Chemical name	Chemical class	Inventory
10043-35-3 <sup>a</sup>	Boric acid (H <sub>3</sub> BO <sub>3</sub> )	Boric acids	DSL
11113-50-1	Boric acid (crude natural)	Boric acids	DSL
13460-50-9	Boric acid (HBO <sub>2</sub> )	Boric acids	DSL
13460-51-0	Metaboric acid	Boric acids	ICL
1303-86-2	Boron oxide (B <sub>2</sub> O <sub>3</sub> )	Boric acids	DSL
11138-47-9	Perboric acid, sodium salt	Borates	DSL
10332-33-9	Perboric acid (HBO(O <sub>2</sub> )), sodium salt monohydrate	Borates	DSL
10486-00-7	Perboric acid (HBO(O <sub>2</sub> )), sodium salt tetrahydrate	Borates	ICL (hydrate)
7632-04-04 <sup>a</sup>	Perboric acid (HBO(O <sub>2</sub> )), sodium salt	Borates	DSL
13840-56-7	Boric acid (H <sub>3</sub> BO <sub>3</sub> ), sodium salt	Borates	DSL
1333-73-9	Boric acid, sodium salt	Borates	DSL
13453-69-5 <sup>a</sup>	Boric acid (HBO <sub>2</sub> ), lithium salt	Borates	DSL
20786-60-1	Boric acid (H <sub>3</sub> BO <sub>3</sub> ), potassium salt	Borates	DSL
7775-19-1	Boric acid (HBO <sub>2</sub> ), sodium salt	Borates	DSL
16800-11-6	Sodium metaborate dihydrate (Na <sub>2</sub> B <sub>2</sub> O <sub>4</sub> ·4H <sub>2</sub> O)	Borates	DSL (hydrate)
10555-76-7	Sodium metaborate tetrahydrate (Na <sub>2</sub> B <sub>2</sub> O <sub>4</sub> ·8H <sub>2</sub> O)	Borates	DSL (hydrate)

CAS RN	Chemical name	Chemical class	Inventory
13701-64-9	Boric acid (HBO <sub>2</sub> ), calcium salt	Borates	DSL
13709-94-9	Boric acid (HBO <sub>2</sub> ), potassium salt	Borates	DSL
13701-59-2	Boric acid (HBO <sub>2</sub> ), barium salt	Borates	DSL
22694-75-3	Boric acid (H <sub>3</sub> BO <sub>3</sub> ), triammonium salt	Borates	ICL
11128-98-6	Boric acid, ammonium salt	Borates	ICL
27522-09-4	Boric acid (H <sub>3</sub> BO <sub>3</sub> ), ammonium salt	Borates	ICL
1330-43-4 <sup>a</sup>	Boron sodium oxide (B <sub>4</sub> Na <sub>2</sub> O <sub>7</sub> )	Borates	DSL
12267-73-1	Boron sodium oxide (B <sub>4</sub> Na <sub>2</sub> O <sub>7</sub> ), hydrate (1:?)	Borates	DSL (hydrate)
12045-88-4	Sodium tetraborate pentahydrate (borax pentahydrate)	Borates	DSL (hydrate)
12179-04-3	Sodium tetraborate pentahydrate	Borates	DSL (hydrate)
1303-96-4 <sup>a</sup>	Borax (B <sub>4</sub> Na <sub>2</sub> O <sub>7</sub> ·10H <sub>2</sub> O)	Borates	DSL
12767-90-7 <sup>a</sup>	Boron zinc oxide (B <sub>6</sub> Zn <sub>2</sub> O <sub>11</sub> )	Borates	DSL
1332-07-6 <sup>a</sup>	Boric acid, zinc salt	Borates	DSL
12447-61-9	Boron zinc oxide (B <sub>6</sub> Zn <sub>2</sub> O <sub>11</sub> ) hydrate (2:15)	Borates	DSL (hydrate)
12280-01-2	Zinc triborate monohydrate	Borates	DSL (hydrate)
138265-88-0	Boron zinc hydroxide oxide (B <sub>12</sub> Zn <sub>4</sub> (OH) <sub>14</sub> O <sub>15</sub> )	Borates	DSL (hydrate)
149749-62-2	Zinc borate (4ZnO·B <sub>2</sub> O <sub>3</sub> ·H <sub>2</sub> O)	Borates	DSL (hydrate)
10192-46-8	Boric acid (H <sub>3</sub> BO <sub>3</sub> ), zinc salt (2:3)	Borates	ICL
12007-60-2 <sup>a</sup>	Boron lithium oxide (B <sub>4</sub> Li <sub>2</sub> O <sub>7</sub> )	Borates	DSL
12007-89-5 <sup>a</sup>	Ammonium boron oxide ((NH <sub>4</sub> )B <sub>5</sub> O <sub>8</sub> )	Borates	DSL
12046-04-7	Borate(5-), bis[m-oxotetraoxodiborato (4-)]-, ammonium tetrahydrogen, dihydrate, (T-4)-	Borates	DSL (hydrate)
12229-12-8	Ammonium pentaborate tetrahydrate	Borates	DSL (hydrate)
12271-95-3 <sup>a</sup>	Boron silver oxide (B <sub>4</sub> Ag <sub>2</sub> O <sub>7</sub> )	Borates	DSL
12008-41-2	Boron sodium oxide (B <sub>8</sub> Na <sub>2</sub> O <sub>13</sub> )	Borates	DSL
12280-03-4	Boron sodium oxide (B <sub>8</sub> Na <sub>2</sub> O <sub>13</sub> ), tetrahydrate	Borates	DSL (hydrate)
1332-77-0	Boron potassium oxide (B <sub>4</sub> K <sub>2</sub> O <sub>7</sub> )	Borates	DSL
12045-78-2	Boron potassium oxide (B <sub>4</sub> K <sub>2</sub> O <sub>7</sub> ), tetrahydrate	Borates	DSL (hydrate)
11128-29-3	Boron potassium oxide (B <sub>5</sub> KO <sub>8</sub> )	Borates	DSL
12229-13-9	Boron potassium oxide (B <sub>5</sub> KO <sub>8</sub> ), tetrahydrate	Borates	DSL (hydrate)

CAS RN	Chemical name	Chemical class	Inventory
1318-33-8	Colemanite ( $\text{CaH}(\text{BO}_2)_3 \cdot 2\text{H}_2\text{O}$ )	Borates	Substance of commercial importance
12291-65-5	Colemanite ( $\text{CaH}(\text{BO}_2)_3 \cdot 2\text{H}_2\text{O}$ )	Borates	Substance of commercial importance
1319-33-1	Ulexite ( $\text{CaNaH}_{12}(\text{BO}_3)_5 \cdot 2\text{H}_2\text{O}$ )	Borates	Substance of commercial importance
68457-13-6 <sup>a</sup>	Cobalt, borate neodecanoate complexes	Borates	DSL
68442-99-9	Manganese, borate neodecanoate complexes	Borates	DSL
102-24-9	Boroxin, trimethoxy-	Borate esters	DSL
102-98-7	Mercurate(2-), [orthoborato(3-)-.k.O]phenyl-, hydrogen (1:2)	Borate esters	ICL
121-43-7	Boric acid ( $\text{H}_3\text{BO}_3$ ), trimethyl ester	Borate esters	DSL
150-46-9	Boric acid ( $\text{H}_3\text{BO}_3$ ), triethyl ester	Borate esters	DSL
2467-16-5	Boric acid ( $\text{H}_3\text{BO}_3$ ), tricyclohexyl ester	Borate esters	DSL
2665-13-6	1,3,2-Dioxaborinane, 2,2'-[(1-methyl-1,3-propanediyl)bis(oxy)]bis[4-methyl-	Borate esters	DSL
5743-34-0	D-Gluconic acid, cyclic 4,5-ester with boric acid ( $\text{H}_3\text{BO}_3$ ), calcium salt (2:1)	Borate esters	DSL
6273-99-0	Mercury, [.μ.-[orthoborato(2-)-.k.O:.k.O']]diphenyldi-	Borate esters	ICL
7091-41-0	2,4,8,10-Tetraoxa-3,9-diborasp[iro[5.5]undecane, 3,9-bis(4-methylphenyl)-	Borate esters	DSL
14697-50-8	1,3,2-Dioxaborinane, 2,2'-oxybis[4,4,6-trimethyl-	Borate esters	DSL
51136-86-8	Hexanoic acid, 2-ethyl-, trianhydride with boric acid ( $\text{H}_3\text{BO}_3$ )	Borate esters	DSL
67859-60-3	Boroxin, tris[(2-ethylhexyl)oxy]-	Borate esters	DSL
68130-12-1	Boric acid, 2-aminoethyl ester	Borate esters	ICL
68298-96-4	Ethanol, 2,2'-iminobis-, monoester with boric acid	Borate esters	DSL
89325-22-4	9-Octadecenoic acid (Z)-, (2-hydroxy-1,3,2-dioxaborolan-4-yl)methyl ester	Borate esters	DSL

CAS RN	Chemical name	Chemical class	Inventory
71889-05-9	Benzenemethanol, 4-amino- $\alpha$ -(4-amino-3,5-dimethylphenyl)- $\alpha$ -(2,6-dichlorophenyl)-3,5-dimethyl-, monoester with boric acid ( $H_3BO_3$ )	Borate esters	DSL
10377-81-8	Ethanol, 2-amino-, monoester with boric acid	Borate esters (monoalkanola mine borate)	DSL
26038-87-9	Boric acid ( $H_3BO_3$ ), compd. with 2-aminoethanol	Borate esters (monoalkanola mine borate)	DSL
26038-90-4	Boric acid ( $H_3BO_3$ ), compd. with 1-amino-2-propanol	Borate esters (monoalkanola mine borate)	DSL
68003-13-4	Boric acid ( $H_3BO_3$ ), compd. with 1-amino-2-propanol (1:1)	Borate esters (monoalkanola mine borate)	ICL
68586-07-2	Boric acid ( $H_3BO_3$ ), compd. with 2-aminoethanol (1:1)	Borate esters (monoalkanola mine borate)	DSL
68797-44-4	Boric acid ( $H_3BO_3$ ), compd. with 2-aminoethanol (1:3)	Borate esters (monoalkanola mine borate)	DSL
93964-50-2	Boric acid ( $H_3BO_3$ ), compd. with 2-amino-2-methyl-1-propanol	Borate esters (monoalkanola mine borate)	DSL
10049-36-2	Boric acid ( $H_3BO_3$ ), compd. with 2,2',2''-nitrilotris[ethanol]	Borate esters (trialkanolamine borate)	DSL
10220-75-4	Boric acid ( $H_3BO_3$ ), compd. with 2,2',2''-nitrilotris[ethanol] (1:1)	Borate esters (trialkanolamine borate)	DSL
64612-24-4	Boric acid ( $H_3BO_3$ ), compd. with 2,2'-iminobis[ethanol] (1:1)	Borate esters (dialkanolamine polyborate)	DSL
67952-33-4	Boric acid ( $H_3BO_3$ ), compd. with 2,2'-iminobis[ethanol]	Borate esters (dialkanolamine polyborate)	DSL
68425-66-1	Boric acid, compd. with 2,2'-iminobis[ethanol]	Borate esters (dialkanolamine polyborate)	DSL
68954-07-4	Boric acid, reaction products with diethanolamine	Borate esters (dialkanolamine polyborate)	DSL

CAS RN	Chemical name	Chemical class	Inventory
68512-53-8	Boric acid (H <sub>3</sub> BO <sub>3</sub> ), reaction products with ethanolamine and triethanolamine	Borate esters (monoalkanola mine / trialkanolamine polyborate)	DSL
75-23-0	Boron, (ethanamine)trifluoro-, (T-4)-	Boron halides	DSL
109-63-7	Boron, trifluoro[1,1'-oxybis[ethane]]-, (T-4)-	Boron halides	DSL
368-39-8	Oxonium, triethyl-, tetrafluoroborate(1-)	Boron halides	DSL
456-27-9	Benzenediazonium, 4-nitro-, tetrafluoroborate(1-)	Boron halides	DSL
592-39-2	Boron, trifluoro(piperidine)-, (T-4)-	Boron halides	DSL
2145-24-6	Benzenediazonium, 4-sulfo-, tetrafluoroborate(1-)	Boron halides	DSL
7445-38-7	Boron, trifluoro[N-(phenylmethyl) benzenemethanamine]-, (T-4)-	Boron halides	DSL
7637-07-2	Borane, trifluoro-	Boron halides	DSL
10294-33-4	Borane, tribromo-	Boron halides	DSL
10294-34-5	Borane, trichloro-	Boron halides	DSL
13755-29-8	Borate(1-), tetrafluoro-, sodium	Boron halides	DSL
13814-96-5 <sup>a</sup>	Borate(1-), tetrafluoro-, lead(2++) (2:1)	Boron halides	DSL
13814-97-6	Borate(1-), tetrafluoro-, tin(2++) (2:1)	Boron halides	DSL
13826-83-0 <sup>a</sup>	Borate(1-), tetrafluoro-, ammonium	Boron halides	DSL
14075-53-7	Borate(1-), tetrafluoro-, potassium	Boron halides	DSL
14486-19-2 <sup>a</sup>	Borate(1-), tetrafluoro-, cadmium (2:1)	Boron halides	DSL
16872-11-0	Borate(1-), tetrafluoro-, hydrogen	Boron halides	DSL
16903-52-9	Borate(1-), trifluorohydroxy-, hydrogen, (T-4)-	Boron halides	DSL
34762-90-8	Boron, trichloro(N,N-dimethyl-1-octanamine)-, (T-4)-	Boron halides	DSL
36936-37-5	Benzeneethanaminium, 4-[[4-[ethyl[2-hydroxy-3-(trimethylammonio)propyl]amino]-2-methylphenyl]azo]-N,N,N-trimethyl-β-oxo-, bis[tetrafluoroborate(1-)]	Boron halides	DSL
72140-65-9	Sulfonium, (2-cyano-1-methylethyl)dodecylethyl-, tetrafluoroborate(1-)	Boron halides	DSL
74-94-2	Boron, trihydro(N-methylmethanamine)-, (T-4)-	Boranes	DSL

CAS RN	Chemical name	Chemical class	Inventory
7337-45-3	Boron, trihydro(2-methyl-2-propanamine)-, (T-4)-	Boranes	DSL
19287-45-7	Diborane	Boranes	DSL
12386-10-6	Methanaminium, N,N,N-trimethyl-, octahydrotriborate(1-)	Boranes	DSL
16940-66-2	Borate(1-), tetrahydro-, sodium	Boranes	DSL
98-80-6	Boronic acid, phenyl-	Organoboron compounds	DSL
143-66-8	Borate(1-), tetraphenyl, sodium	Organoboron compounds	DSL
3262-89-3	Boroxin, triphenyl	Organoboron compounds	DSL
13331-27-6	Boronic acid, (3-nitrophenyl)-	Organoboron compounds	DSL
66472-86-4	Boronic acid, (3-aminophenyl)-, sulfate (2:1)	Organoboron compounds	DSL
39405-47-5	Dextrin, reaction products with boric acid	UVCBs	DSL
58450-10-5	D-gluco-Heptonic acid, (2ξ)-, ester with boric acid (H <sub>3</sub> BO <sub>3</sub> ), sodium salt	UVCBs	DSL
68131-51-1	Caseins, borated	UVCBs	DSL
68411-21-2	Boric acid (HB <sub>5</sub> O <sub>8</sub> ), sodium salt, reaction products with propylene glycol	UVCBs	DSL
68411-22-3	Phosphoric acid, reaction products with aluminum hydroxide and boric acid (H <sub>3</sub> BO <sub>3</sub> )	UVCBs	DSL
68511-18-2	Starch, borate	UVCBs	DSL
68610-78-6	Acetic acid, anhydride, reaction products with boron trifluoride and 1,5,9-trimethyl-1,5,9-cyclododecatriene	UVCBs	DSL
68855-38-9	Formic acid, reaction products with boron trifluoride and [1S-(1α,3aβ,4α,8aβ)]-decahydro-4,8,8-trimethyl-9-methylene-1,4-methanoazulene	UVCBs	DSL
69898-30-2	Starch, base-hydrolyzed, borated	UVCBs	DSL
72066-70-7	Sulfite liquors and cooking liquors, spent, borated	UVCBs	DSL
90530-04-4	2-Propanol, reaction products with boron trifluoride and 5-ethylidenebicyclo[2.2.1]hept-2-ene	UVCBs	DSL

CAS RN	Chemical name	Chemical class	Inventory
91770-03-5	Fatty acids, tall-oil, reaction products with boric acid (H <sub>3</sub> BO <sub>3</sub> ) and diethanolamine	UVCBs	DSL
91782-44-4	1,2-Ethenediol, reaction products with boron sodium oxide (B <sub>4</sub> Na <sub>2</sub> O <sub>7</sub> )	Organics	DSL
93924-91-5	Boric acid (H <sub>3</sub> BO <sub>3</sub> ), reaction products with 2,2'-[(C16-18 and C16-18-unsaturated alkyl)imino]bis[ethanol]	UVCBs	DSL
121053-02-9	Sulfonic acids, petroleum, calcium salts, overbased, reaction products with acetic acid, boric acid and 12-hydroxyoctadecanoic acid	UVCBs	DSL
124751-09-3	Caseins, reaction products with ammonium hydroxide, boron sodium oxide (B <sub>4</sub> Na <sub>2</sub> O <sub>7</sub> ), sodium hydroxide and trisodium phosphate	UVCBs	DSL
125328-30-5	Starch, acid-hydrolyzed, borated	UVCBs	DSL
127087-85-8	Boric acid (H <sub>3</sub> BO <sub>3</sub> ), reaction products with 2-(butylamino)ethanol and diethanolamine	UVCBs	DSL
129783-46-6	Borate(1-), tetrafluoro-, hydrogen, reaction products with 2-(ethylthio)ethanol	UVCBs	DSL

Abbreviations: ICL, In-Commerce List; UVCB, Substance of Unknown or Variable composition, Complex reaction products or Biological materials.

<sup>a</sup> Substance found to meet categorization criteria under subsection 73(1) of CEPA.

**Table A-2: Substances considered non-precursors of boric acid**

CAS RN	Chemical name	Chemical class	Inventory
7440-42-8	Boron	Elemental boron	DSL
50815-87-7	Sodium borate silicate	Borates	DSL
59794-15-9	Calcium borate silicate	Borates	DSL
65997-17-3	Glass, oxide, chemicals	Borates	DSL/ICL
10043-11-5	Boron nitride (BN)	Borides	DSL
12008-21-8	Lanthanum boride (LaB <sub>6</sub> ), (OC-6-11)-	Borides	DSL
12045-63-5	Titanium boride (TiB <sub>2</sub> )	Borides	DSL
12069-32-8	Boron carbide (B <sub>4</sub> C)	Borides	DSL

## Appendix B: Aquatic Ecotoxicological Data

**Table B-1: Chronic toxicity data set used to develop the SSD-based water quality guideline (CCME 2009)**

Group	Species name (common name)	Endpoint and duration	Response	Effects concentration mg B/L (geomean)	Reference
Algae	<i>Elodea canadensis</i> (American Waterweed)	NOEC	Growth	1.0	ANZECC 2000
Algae	<i>Spirodela polyrhiza</i> (duckweed)	10-d MATC	Fronnd production	1.8 (geomean; n=2)	Davis et al. 2002
Algae	<i>Chlorella pyrenoidosa</i> (green algae)	14-d NOEC	Growth or cell composition	2.0 (geomean; n=2)	ANZECC 2000; Fernandez et al. 1984
Fish	<i>Oncorhynchus mykiss</i> (Rainbow Trout)	87-d NOEC	Embryo survival	2.1	Black et al. 1993
Fish	<i>Ictalurus punctatus</i> (Channel Catfish)	9-d MATC	Survival	2.4 (geomean; n=8)	Birge and Black 1977
Plant	<i>Phragmites australis</i> (Common Reed)	4-mo NOEC	Growth	4.0	Bergmann 1995
Fish	<i>Micropterus salmoides</i> (Largemouth Bass)	11-d MATC	Teratogenesis	4.1 (geomean; n=2)	Black et al. 1993
Algae	<i>Chlorella vulgaris</i> (green algae)	NOEC	Population growth	5.2	ANZECC 2000
Invertebrate	<i>Daphnia magna</i> (water flea)	NOEC	Reproduction	6.0	ANZECC 2000
Protozoa	<i>Opercularia bimarginata</i>	72-hr NOEC	Growth, reproduction	10.0	Guhl 1992a
Fish	<i>Danio rerio</i> (Zebrafish)	34-d MATC	Mortality, growth condition	10.0	Hoofman et al. 2000b

Algae	<i>Selenastrum capricornutum</i> (green algae)	72-hr LOEC	Growth	12.3	MELP 1997
Invertebrate	<i>Ceriodaphnia dubia</i> (water flea)	14-d MATC	Growth, reproduction	13.4	Hickey 1989
Invertebrate	<i>Entosiphon sulcatum</i> (zooplankton)	72-hr NOEC	Growth	15.0	Guhl 1992a
Fish	<i>Carassius auratus</i> (Goldfish)	7-d MATC	Survival and teratogenesis	15.6 (geomean; n=8)	Birge and Black 1977
Fish	<i>Pimephales promelas</i> (Fathead Minnow)	30-d MATC	Growth reduction	18.3 (geomean; n=2)	Procter and Gamble 1979
Invertebrate	<i>Chironomus decorus</i> (Midge)	96-hr NOEC	Growth	20.0	Maier and Knight 1991
Ciliate	<i>Paramecium caudatum</i>	72-hr NOEC	Growth, reproduction	20.0	Guhl 1992a
Amphibian	<i>Rana pipiens</i> (Leopard Frog)	7-d MATC	Survival and teratogenesis	20.4 (geomean; n=8)	Birge and Black 1977; Butterwick et al. 1989; Eisler 1990
Algae	<i>Scenedesmus subspicatus</i> (green algae)	96-hr EC <sub>10</sub>	Growth	30.0	Guhl 1992b
Algae	<i>Myriophyllum spicatum</i> (Spiked or Eurasian Watermilfoil)	NOEC	Growth	34.2	ANZECC 2000
Amphibian	<i>Bufo fowleri</i> (Fowler's Toad)	7-d MATC	Survival and teratogenesis	48.6	Birge and Black 1977
Algae	<i>Aspergillus nidulans</i> (blue-green algae)	NOEC	Growth or organic constituents	50.0	Martinez et al. 1986
Amphibian	<i>Bufo americanus</i> (American Toad)	43-d LOEC	Proportion of eggs hatching	50.0	Laposata and Dunson 1998

Algae	<i>Lemna minor</i> (duckweed)	7-d NOEC	Growth	60.0	Wang 1986
Amphibian	<i>Ambystoma jeffersonianum</i> (Jefferson's Salamander)	17 to 25- d MATC	Proportion of deformed hatchlings	70.7 (geomean; n=2)	Laposata and Dunson 1998
Amphibian	<i>Ambystoma maculatum</i> (Spotted Salamander)	38 to 44- d MATC	Proportion of deformed hatchlings	70.7 (geomean; n=2)	Laposata and Dunson 1998
Amphibian	<i>Rana sylvatica</i> (Wood Frog)	13 to 23- d MATC	Proportion of eggs hatched	70.7 (geomean; n=2)	Laposata and Dunson 1998

**Table B-2: Available sediment toxicity data**

Group	Species name (common name)	Endpoint and duration	Response	Effects concentration	Reference
Invertebrate	<i>Chironomus riparius</i> (Freshwater Midge)	28-d NOEC	Multiple <sup>a</sup>	37.8 mg B/kg	Gerke et al. 2011a <sup>b</sup>
Invertebrate	<i>Chironomus riparius</i>	28-d LOEC	Multiple <sup>a</sup>	> 37.8 mg B/kg	Gerke et al. 2011a <sup>b</sup>
Invertebrate	<i>Chironomus riparius</i>	28-d NOEC	Survival, emergence	20.4 mg B/L	Gerke et al. 2011b <sup>c</sup>
Invertebrate	<i>Chironomus riparius</i>	28-d LOEC	Survival, emergence	43.3 mg B/L	Gerke et al. 2011b <sup>c</sup>
Invertebrate	<i>Chironomus riparius</i>	28-d EC <sub>10</sub>	Survival	43 mg B/L	Gerke et al. 2011b <sup>c</sup>
Invertebrate	<i>Chironomus riparius</i>	28-d EC <sub>50</sub>	Survival	46.5 mg B/L	Gerke et al. 2011b <sup>c</sup>
Invertebrate	<i>Chironomus riparius</i>	28-d EC <sub>10</sub>	Emergence	40.8 mg B/L	Gerke et al. 2011b <sup>c</sup>
Invertebrate	<i>Chironomus riparius</i>	28-d EC <sub>50</sub>	Emergence	50.2 mg B/L	Gerke et al. 2011b <sup>c</sup>
Invertebrate	<i>Chironomus riparius</i>	28-d NOEC	Multiple <sup>d</sup>	43.3 mg B/L	Gerke et al. 2011b <sup>c</sup>
Invertebrate	<i>Chironomus riparius</i>	28-d LOEC	Multiple <sup>d</sup>	> 43.3 mg B/L	Gerke et al. 2011b <sup>c</sup>
Invertebrate	<i>Chironomus riparius</i>	28-d NOEC	Mortality, emergence	180 mg B/kg	Hooftman et al. 2000a

Invertebrate	<i>Chironomus riparius</i>	28-d LOEC	Mortality, emergence	320 mg B/kg	Hoofman et al. 2000a
Invertebrate	<i>Chironomus riparius</i>	28-d LC <sub>50</sub>	Mortality	278 mg B/kg	Hoofman et al. 2000a
Invertebrate	<i>Chironomus riparius</i>	28-d NOEC	Mortality, emergence	32 mg B/L	Hoofman et al. 2000a
Invertebrate	<i>Chironomus riparius</i>	28-d LOEC	Mortality, emergence	59 mg B/L	Hoofman et al. 2000a
Invertebrate	<i>Chironomus riparius</i>	28-d LC <sub>50</sub>	Mortality	49 mg B/L	Hoofman et al. 2000a
Invertebrate	<i>Lampsilis siliquoidea</i> (Fatmucket Clam)	21-d NOEC	Survival	254.9 mg B/kg	Hall et al. 2014
Invertebrate	<i>Lampsilis siliquoidea</i>	21-d IC <sub>25</sub>	Survival	363.1 mg B/kg	Hall et al. 2014
Invertebrate	<i>Lampsilis siliquoidea</i>	21-d NOEC	Survival	31.6 mg B/L	Hall et al. 2014
Invertebrate	<i>Lampsilis siliquoidea</i>	21-d IC <sub>25</sub>	Survival	45.0 mg B/L	Hall et al. 2014
Invertebrate	<i>Lampsilis siliquoidea</i>	21-d NOEC	Growth	80.6 mg B/kg	Hall et al. 2014
Invertebrate	<i>Lampsilis siliquoidea</i>	21-d IC <sub>25</sub>	Growth	310.6 mg B/kg	Hall et al. 2014
Invertebrate	<i>Lampsilis siliquoidea</i>	21-d NOEC	Growth	10 mg B/L	Hall et al. 2014
Invertebrate	<i>Lampsilis siliquoidea</i>	21-d IC <sub>25</sub>	Growth	38.5 mg B/L	Hall et al. 2014
Invertebrate	<i>Lumbriculus variegatus</i> (aquatic worm)	28-d NOEC	Survival	100.8 mg B/kg	Hall et al. 2014
Invertebrate	<i>Lumbriculus variegatus</i>	28-d NOEC	Survival	12.5 mg B/L	Hall et al. 2014
Invertebrate	<i>Lumbriculus variegatus</i>	28-d IC <sub>25</sub>	Survival	12.7 mg B/L	Hall et al. 2014
Invertebrate	<i>Lumbriculus variegatus</i>	28-d NOEC	Growth	201.6 mg B/kg	Hall et al. 2014
Invertebrate	<i>Lumbriculus variegatus</i>	28-d IC <sub>25</sub>	Growth	235.5 mg B/kg	Hall et al. 2014
Invertebrate	<i>Lumbriculus variegatus</i>	28-d NOEC	Growth	25 mg B/L	Hall et al. 2014
Invertebrate	<i>Lumbriculus variegatus</i>	28-d IC <sub>25</sub>	Growth	25.9 mg B/L	Hall et al. 2014

<sup>a</sup> Survival, emergence, emergence time (male, female, total), development rate (male, female, total).

<sup>b</sup> Test conducted using spiked sediments.

<sup>c</sup> Test conducted using spiked water.

<sup>d</sup> Emergence time (male, female, total), development rate (male, female, total).

## Appendix C: Soil Ecotoxicological Data

Table C-1: Chronic toxicity data set used to develop the SSD for soil

Group	Species name (common name)	Endpoint and duration	Response	Effects concentration mg B/kg (geomean)	Reference
Invertebrate	<i>Folsomia candida</i> (springtail)	28 to 42-d EC <sub>10</sub>	Reproduction	5.5	Amorim et al. 2012
Plant (monocot)	<i>Zea mays</i> (corn)	70-d EC <sub>10</sub>	Growth (yield shoot)	7.2	ARCHE 2010; Hosseini et al. 2007
Invertebrate	<i>Enchytraeus albidus</i> (White Worm)	28 to 42-d EC <sub>10</sub>	Reproduction	8.5 (geomean, n=2)	Amorim et al. 2012
Plant (monocot)	<i>Elymus lanceolatus</i> (Northern Wheatgrass)	21-d IC <sub>20</sub>	Emergence	9.6	Anaka et al. 2007
Plant (monocot)	<i>Avena sativa</i> (oat)	14-d EC <sub>10</sub>	Shoot biomass	11	Förster and Becker 2009
Plant (dicot)	<i>Medicago sativa</i> sp (Alfalfa)	45-d NOEC	Yield shoot	13.35 (geomean; n=12)	Gestring and Soltanpour 1987
Plant (dicot)	<i>Brassica napus</i> (Rapeseed)	14-d EC <sub>10</sub>	Shoot biomass	13.9	Förster and Becker 2009
Invertebrate	<i>Enchytraeus luxuriosus</i> (earthworm)	28-d EC <sub>10</sub>	Reproduction	17	Moser and Beker 2009d
Invertebrate	<i>Enchytraeus crypticus</i> (earthworm)	28-d EC <sub>10</sub>	Reproduction	22.5	Moser and Beker 2009c
Invertebrate	<i>Hypoaspis aculeifer</i> (Predatory Mite)	14-d EC <sub>10</sub>	Reproduction	22.7	Moser and Scheffczyk 2009
Invertebrate	<i>Onychiurus folsomi</i>	35-d EC <sub>20</sub>	Reproduction	24.1 (geomean; n=2)	ESG International Inc. and Aquatera Environmental Consulting Ltd. 2003

Invertebrate	<i>Eisenia andrei</i> (earthworm)	56 to 63-d IC <sub>20</sub>	Reproduction (juvenile dry mass)	24.8 (geomean; n=6)	Stantec and Aquaterra Consulting 2004
Plant (tree)	<i>Picea glauca</i> (White Spruce)	35-d IC <sub>25</sub>	Root length	27.7 (geomean n=3)	Environment Canada 2014
Plant (tree)	<i>Betula papyrifera</i> (Paper Birch)	28-d IC <sub>25</sub>	Root length	28.25 (geomean; n=3)	Environment Canada 2014
Plant (monocot)	<i>Calamagrosti s canadensis</i> (Bluejoint Reedgrass)	14-d IC <sub>25</sub>	Root length	36.45 (geomean; n=4)	Environment Canada 2014
Plant (tree)	<i>Populus tremuloides</i> (White Poplar)	21-d IC <sub>25</sub>	Root length	42.7 (geomean; n=3)	Environment Canada 2014
Invertebrate	<i>Poecilus cupreus</i> (ground beetle)	21-d EC <sub>10</sub>	Feeding rate	47.5	Moser and Becker 2009e
Plant (eudicot)	<i>Solidago canadensis</i> (Canada Goldenrod)	21-d IC <sub>25</sub>	Shoot length	48.1 (geomean; n=3)	Environment Canada 2014
Invertebrate	<i>Dendrodrilus rubidus</i> (earthworm)	56-d IC <sub>25</sub>	Reproduction	58.8 (geomean; n=2)	Environment Canada 2014
Plant (tree)	<i>Picea mariana</i> (Black Spruce)	35-d IC <sub>25</sub>	Root length	60.2 (geomean; n=5)	Environment Canada 2014
Plant (tree)	<i>Pinus banksiana</i> (Jack Pine)	14-d IC <sub>25</sub>	Root length	61.1 (geomean; n=3)	Environment Canada 2014
Invertebrate	<i>Eisenia fetida</i> (Tiger Worm)	56-d EC <sub>10</sub>	Reproduction	70.1	Moser and Becker 2009a
Invertebrate	<i>Caenorhabditis elegans</i> (nematode)	4-d EC <sub>10</sub>	Reproduction	86.7	Moser and Becker 2009b

## Appendix D: Estimated Intakes from Environmental Media, Food and Drinking Water

**Table D-1: Average estimates of daily intake ( $\mu\text{g B/kg bw/d}$ ) of boric acid by the general population in Canada through environmental media and food**

Route of exposure	0–6 months breast fed <sup>a,b</sup>	0.5–4 years <sup>c</sup>	5–11 years <sup>d</sup>	12–19 years <sup>e</sup>	20–59 years <sup>f</sup>	60+ years <sup>g</sup>
Air <sup>h</sup>	0.001	0.003	0.002	0.001	0.001	0.001
Food and water <sup>i</sup>	3.0	91.7	63.6	26.2	24.7	23.2
Soil <sup>j</sup>	NA	0.030	0.022	0.001	0.001	0.001
Dust <sup>k</sup>	0.331	0.173	0.065	0.002	0.002	0.002
Total intake	3.3	91.9	63.7	26.2	24.7	23.2

NA: not applicable

<sup>a</sup> Assumed to weigh 7.5 kg, to breathe 2.1 m<sup>3</sup> of air per day (Health Canada 1998), and to ingest 38 mg of household dust per day (Wilson et al. 2013). Breastfed infants are assumed to consume solely breast milk for six months.

<sup>b</sup> Assumed to consume 0.742 L of breast milk per day (Health Canada 1998). The average concentration measured in breast milk in women from St. John's, NL, was 30  $\mu\text{g/L}$  (Hunt 2004), and the maximum measured concentration was 100  $\mu\text{g/L}$  (ATSDR 2010).

<sup>c</sup> Assumed to weigh 15.5 kg, to breathe 9.3 m<sup>3</sup> of air per day (Health Canada 1998), and to ingest 14 mg of soil and 41 mg of household dust per day (Wilson et al. 2013). Median dietary intake estimates (food and drinking water) for 1–3 years, as presented in Table 9-1, were used to represent dietary intake for this age group.

<sup>d</sup> Assumed to weigh 31.0 kg, to breathe 14.5 m<sup>3</sup> of air per day (Health Canada 1998), and to ingest 21 mg of soil and 31 mg of household dust per day (Wilson et al. 2013). Median dietary intake estimates (food and drinking water) for 4–8 years, as presented in Table 9-1, were used to represent dietary intakes for this age group.

<sup>e</sup> Assumed to weigh 59.4 kg, to breathe 15.8 m<sup>3</sup> of air per day (Health Canada 1998), and to ingest 1.4 mg of soil and 2.2 mg of household dust per day (Wilson et al. 2013). Median dietary intake estimates (food and drinking water) for males 14–18 years, as presented in Table 9-1, were used to represent dietary intakes for this age group.

<sup>f</sup> Assumed to weigh 70.9 kg, to breathe 16.2 m<sup>3</sup> of air per day (Health Canada 1998), and to ingest 1.6 mg of soil and 2.5 mg of household dust per day (Wilson et al. 2013). Median dietary intake estimates (food and drinking water) for females 19–30 years, as presented in Table 9-1, were used to represent dietary intakes for this age group.

<sup>g</sup> Assumed to weigh 72.0 kg, to breathe 14.3 m<sup>3</sup> of air per day (Health Canada 1998), and to ingest 1.5 mg of soil and 2.5 mg of household dust per day (Wilson et al. 2013). Median dietary intake estimates (food and drinking water) for females 51–70 years, as presented in Table 9-1, were used to represent dietary intakes for this age group.

<sup>h</sup> Intake estimated using median 24-hr personal air sample PM<sub>10</sub> concentration of 5.3  $\text{ng/m}^3$  (n=127), measured in Windsor, Ontario (Rasmussen et al. 2013). Personal air data are considered to be most representative of air concentrations in the breathing zone.

<sup>i</sup> Median usual dietary intake (food and drinking water) is presented (with the exception of breastfed infants). The age groups from the dietary exposure assessment groups (as presented in Table 9-1) that overlap the most with age groups presented in Table D-1 were used (2013, 2014 emails from the Food Directorate, Health Canada to the Existing Substances Risk Assessment Bureau, Health Canada; unreferenced). For breastfed infants, see b above.

<sup>j</sup> Intake based on the average concentration of total boron in U.S. soils (33  $\mu\text{g/g}$ ) (USGS 1984); adequate Canadian data were not available.

<sup>k</sup> Intake based on median national baseline concentration of bioaccessible boron of 65 µg/g measured in 1025 homes in the Canadian House Dust Study (Rasmussen et al. 2014 – paper submitted for publication).

## Appendix E: Estimated Intakes from the Use of Products

**Table E-1: Arts, crafts and toys — Estimated intakes of boron for children playing with homemade modelling clay**

Scenario	Age group	Body weight (kg)	Boron concentration (%)	Product amount	Dermal absorption (%)	Intake ( $\mu\text{g}/\text{kg bw}/\text{d}$ )
Direct ingestion from playing with modelling clay <sup>a</sup>	6 m to 4 yr	15.5	0.874 (5% boric acid)	100 mg to 5 g ingested	n/a	56–2819
Dermal exposure from playing with modelling clay <sup>b</sup>	6 m to 4 yr	15.5	0.874 (5% boric acid)	350 g	0.5 and 10	69–1381

<sup>a</sup> Where oral ingestion = amount of product ingested (100 mg from RIVM 2008, 5 g internal default for intentional ingestion) \* boron concentration (ECHA 2010; Rio Tinto 2015; Health Canada 2002, 2004, 2009b, 2009c) / kg bw. There may be slight differences due to rounding.

<sup>b</sup> Where dermal exposure = product amount handled (350 g RIVM 2002) \* boron concentration (ECHA 2010; Rio Tinto 2015; Health Canada 2002, 2004, 2009b, 2009c) \* leaching from simulated sweat \* dermal absorption / kg bw. 7% of the boric acid in clay leached onto skin by simulated sweat (BfR 2005). 7% based on 0.1 g boric acid leaching onto skin from 17g clay that contained 1.36g of boric acid (8% x 17g). There may be slight differences due to rounding.

**Table E-2: Cleaning products — Estimated intakes of boron from the use of cleaning products**

Product	Scenario	Age group	Boron concentration (%)	Dermal intake ( $\mu\text{g}/\text{kg bw}/\text{d}$ )	Inhalation intake ( $\mu\text{g}/\text{kg bw}/\text{d}$ )	Oral intake ( $\mu\text{g}/\text{kg bw}/\text{d}$ )
General purpose cleaner (liquid) <sup>a</sup>	Surface cleaning (application)	Adult	0.742	10–199	na	na
Dishwashing detergent (liquid) <sup>b</sup>	Hand-washing (application)	Adult	0.148	4–86	na	na
Floor cleaner (liquid) <sup>c</sup>	Hand-washing (application)	Adult	1.759	27–542	na	na
Floor cleaner (liquid) <sup>d,e</sup>	Post-application dermal from crawling on floor and oral hand-to-mouth	Toddler	1.759	8–160	na	120
Laundry detergent	Laundry additive	Adult	11.4	na	0.02	na

Product	Scenario	Age group	Boron concentration (%)	Dermal intake (µg/kg bw/d)	Inhalation intake (µg/kg bw/d)	Oral intake (µg/kg bw/d)
(powder) <sup>f</sup>	(loading)					

na = not applicable

<sup>a</sup> Based on ConsExpo (2006), where dermal intake = boron concentration \* amount of product contacted (19 g, based on film thickness where 1900 cm<sup>2</sup> surface area contacted and 0.01 cm layer of product on skin \* 1 g/cm<sup>3</sup> density, RIVM 2006) \* dermal absorption (0.5, 10%) / 70.9 kg bw. There may be slight differences due to rounding.

<sup>b</sup> Based on ConsExpo (2006), where dermal intake = boron concentration (cleaning products found on the Canadian market from MSDS search) \* amount of product contacted (20.58 g, based on film thickness, where 2058 cm<sup>2</sup> is the surface area of skin contacted (HERA 2005 values for hands and forearms \* 0.01 cm layer of product on skin \* 1 g/cm<sup>3</sup> density, RIVM 2006) \* dermal absorption (0.5, 10%) \* 2 times use per day (internal default) / 70.9 kg bw. There may be slight differences due to rounding.

<sup>c</sup> Based on ConsExpo (2006), where dermal intake = boron concentration (cleaning products found on the Canadian market from MSDS search) \* product amount in contact with skin (21.85 g, based on surface area of 2185 cm<sup>2</sup> from hands and ½ arms and film thickness of 0.01 cm layer on skin and 1 g/cm<sup>3</sup> density, RIVM 2006) \* dermal absorption (0.5, 10%) / 70.9 kg bw. There may be slight differences due to rounding.

<sup>d</sup> Based on US EPA (2012b) Residential SOPs, where dermal intake = surface residue 40 mL product/m<sup>2</sup> (based on ConsExpo default of 40 mL product/m<sup>2</sup> surface, assuming a density of 1 g/ml) \* boron concentration \* 0.08 floor-to-skin transfer efficiency (US EPA 2012b default for hard surfaces) \* 2200 cm<sup>2</sup>/hr transfer coefficient (US EPA 2012b default of 1800 cm<sup>2</sup>/hr for hard surfaces and carpets adjusted for surface area of 0.5–4 yrs. child) \* 2 hrs exposure duration (US EPA 2012b default for hard surfaces) \* dermal absorption (0.5, 10%) \* conversion factors (1m<sup>2</sup> / 10000cm<sup>2</sup>, 1000000 µg/g) / 15.5 kg bw.

<sup>e</sup> Based on US EPA (2012b) for oral hand-to-mouth intake = [hand residue loading (mg/cm<sup>2</sup>) \* surface area mouthed (22 cm<sup>2</sup>/event)] \* [exposure time (2 hr/day) \* number of replenishment intervals per hr (4 intervals/hr)] \* [1 - (1-saliva extraction factor, 0.48)<sup>frequency of hand-to-mouth, 20 / number of replenishments, 4</sup>] / 15.5 kg bw, where hand residue loading (mg/cm<sup>2</sup>) = fraction of substance on hands compared to total surface residue from jazzercise study (0.15) \* total dermal deposition calculated from dermal scenario (mg/day) / surface areas of both hands (350 cm<sup>2</sup>). There may be slight differences due to rounding.

<sup>f</sup> Based on Pesticide Handlers Exposure Database (PHED), where inhalation intake = 56.20 µg exposure/kg boron handled (PHED unit exposure value M/L wettable powder, Pellerin et al. 2001) \* boron concentration (cleaning products found on the Canadian market) \* product amount handled (227g, 1 cup, default) / 70.9 kg bw. There may be slight differences due to rounding. Only inhalation intake was quantified as it was considered to be more relevant than dermal intake for this scenario.

**Table E-3: Cosmetics — Estimated intakes of boron from cosmetics applied dermally**

Product	Age group	Amount applied <sup>a</sup> (g)	Frequency per day <sup>a</sup>	Retention factor <sup>a</sup>	Dermal absorption (%)	Intake (µg/kg bw/d) <sup>b</sup>
Body cream	20–59	4.4	1.1	1	0.5, 10	3–6
Body cream	5–11	2.2	1.1	1	0.5, 10	3–68
Body cream	0.5–4	1.4	1.7	1	0.5, 10	7–134
Body cream	< 0.5	1.4	1.7	1	0.5, 10	14–277

Product	Age group	Amount applied <sup>a</sup> (g)	Frequency per day <sup>a</sup>	Retention factor <sup>a</sup>	Dermal absorption (%)	Intake (µg/kg bw/d) <sup>b</sup>
Skin cleanser	20–59	11.3	1.37	0.01	0.5, 10	0.1–1.9
Skin cleanser	5–11	6.48	0.42	0.01	0.5, 10	0.04–0.8
Skin cleanser	0.5–4	3.76	0.42	0.01	0.5, 10	0.04–0.9
Skin cleanser	< 0.5	0.873	0.64	0.01	0.5, 10	0.03–0.65
Diaper cream	0.5–4	0.3	4	1	100	677
Diaper cream	< 0.5	0.3	4	1	100	1399

<sup>a</sup> Internal default values, amount applied and frequency per day for diaper cream are based on professional judgement.

<sup>b</sup> Based on ConsExpo (2006), where intake = product amount applied \* 0.874% boron (maximum permissible concentration in the Hotlist; Health Canada 2014a) \* frequency per day \* retention factor \* dermal absorption / bw. Body weights for age groups — 20–59 years: 70.9 kg; 5–11 years: 31kg; 0.5–4 years: 15.5 kg; < 0.5 years: 7.5kg (Health Canada 1998). There may be slight differences due to rounding.

**Table E-4: Cosmetics — Estimated intakes of boron for adults from cosmetics with potential for oral and mucosal exposure**

Product	Concentration (% B) <sup>a</sup>	Amount ingested / available for absorption <sup>b</sup>	Frequency per day <sup>b</sup>	Intake (µg/kg bw/d) <sup>c</sup>
Mouthwash	0.175	0.7 g	3	52
Lipstick	0.525	0.01 g	2.4 <sup>c</sup>	2
Genital lubricant	0.525	10 g	1 <sup>b</sup>	740

<sup>a</sup> Maximum concentration reported to Health Canada.

<sup>b</sup> Internal default values, amount applied and frequency per day for genital lubricant are based on professional judgement.

<sup>c</sup> Based on ConsExpo (2006), where intake = boron concentration \* amount ingested / amount available for absorption \* frequency \* 100% dermal absorption (where relevant) / 70.9 kg bw. There may be slight differences due to rounding.

**Table E-5: Natural health products — Estimated intakes of boron for adults taking oral supplements**

Product	Amount of boron in oral supplement (µg) <sup>a</sup>	Intake (µg/kg bw/d) <sup>b</sup>
Multi-vitamin/mineral supplement	700	10
Joint health supplement	3360	47

<sup>a</sup> Health Canada 2007a, 2007b, 2014b.

<sup>b</sup> Where intake = amount of boron in oral supplement / 70.9 kg bw.

**Table E-6: Swimming pool and spa products — Estimated intakes of boron from swimming pools**

Age	BW (kg) <sup>a</sup>	Whole-body surface area (cm <sup>2</sup> ) <sup>b</sup>	Oral ingestion rate (L/hr) <sup>c</sup>	Dermal intake <sup>d</sup> (µg/kg/event)	Oral intake <sup>e</sup> (µg/kg bw/event)	Total intake <sup>f</sup> (µg/kg bw/event)
0–6m	7.5	3680	0.05	18	500	518
6m–4yr	15.5	5780	0.05	14	242	256
5–11yr	31.0	9660	0.05	12	121	133
12–19yr	59.4	16 200	0.05	10	63	73
20–59 yr	70.9	18 200	0.025	10	26	36
60+ yr	72.0	18 200	0.025	9	26	36

<sup>a</sup> Health Canada 1998.

<sup>b</sup> Health Canada 1995.

<sup>c</sup> US EPA 2003 SWIMODEL (Table 3-5); US EPA 2011.

<sup>d</sup> Based on algorithms from US EPA (2003) SWIMODEL, where dermal intake (µg/kg bw/d) = surface area (cm<sup>2</sup>) \* exposure duration (1.5 h, Schets et al. 2011) \* concentration (50 µg B/mL, 50 ppm) \* K<sub>p</sub> (0.0005 cm/h, Wester et al. 1998b) \* conversion factor (1 cm<sup>3</sup> / 1 mL) / bw (kg). There may be slight differences due to rounding.

<sup>e</sup> Based on algorithms from US EPA (2003) SWIMODEL, where oral intake (µg/kg bw/d) = oral ingestion rate (L/h) \* exposure duration (1.5 h, Schets et al. 2011) \* concentration 50 ppm (µg B/mL) \* conversion factor (1000 mL/L) / bw (kg). There may be slight differences due to rounding.

<sup>f</sup> Total intake (µg/kg bw/d) = dermal intake + oral intake. There may be slight differences due to rounding.

## Appendix F: Biomonitoring Data Tables

**Table F-1: Blood boron concentrations in humans – general population (µg/L)**

Population	Age group	Sex	n	Mean ± SD µg/L	Range µg/L	Reference
Alberta, pregnant women, serum	< 25–31+	F	151 pools n=50599	13–34 mean of pools	na	Alberta Health and Wellness 2008
Alberta, pregnant women, serum	18–25	F	54 pools	21.5	na	Government of Alberta 2010
Alberta, pregnant women, serum	26–30	F	50 pools	24	na	Government of Alberta 2010
Alberta, pregnant women, serum	31+	F	47 pools	25	na	Government of Alberta 2010
Alberta, children, serum	< 5–13 (2–13)	M+F	6 pools n= 1373	29–33 means of pools	na	Government of Alberta 2010
Alberta, children, serum	≤ 5 (2 – ≤ 5)	M+F	3 pools	31.5	na	Government of Alberta 2010
Alberta, children, serum	6–13	M+F	3 pools	30.5	na	Government of Alberta 2010
Canada, healthy volunteers, whole blood	Adult	na	12	30.8 ± 5.6	15.3–79.5	Clarke et al. 1987a
Canada, healthy volunteers, blood	Adult	M+F	7	97 ± 22	na	Clarke et al. 1987b
Canada, healthy volunteers (controls), whole blood	Adult	M+F	7	23 ± 2	na	Clarke et al. 2004
Canada, healthy volunteers	Adult	M+F	7	28 ± 2	na	Clarke et al. 2004

Population	Age group	Sex	n	Mean $\pm$ SD $\mu\text{g/L}$	Range $\mu\text{g/L}$	Reference
(controls), plasma						
U.S., plasma	Na	na	12	25 $\pm$ 7	14–39	Ferrando et al. 1993
U.S., non-pregnant women, plasma	18–40	F	15	22 $\pm$ 13	na	Pahl et al. 2001
U.S., pregnant women, plasma	18–40	F	16	23 $\pm$ 15	na	Pahl et al. 2001
UK, whole blood	na	na	50	56.7	8.4–170.4	Abou-Shakra et al. 1989
UK, serum	na	na	50	22.3	8.3–48.1	Abou-Shakra et al. 1989
Sweden, athletes, blood	16–36	M+F	31	11 $\pm$ 7	6–33	Rodushkin et al. 1999
Belgium, serum	23–51	M+F	12	13.9 $\pm$ 6.9	4.1–25.8	Vanhoe et al. 1993
Northern Germany, blood	18–70	M+F	130	42	12–195	Heitland and Köster 2006
Northern France, plasma	21.2 (mean)	M	180	126.11 $\pm$ 106.27	Na	Yazbeck et al. 2005
France, whole blood	na	na	100	Median 26	P5–P95 14–44	Gouille et al. 2005
France, plasma	na	na	100	Median 36	P5–P95 19–79	Gouille et al. 2005
Turkey, plasma	44 (mean)	M+F	80	11.3 $\pm$ 7.9 to 18.3 $\pm$ 19.5 means by body mass index	Na	Hasbachecei et al. 2013
Japan, serum	< 20–80+	F	583	GM 67.9	19.6–211.3	Usuda et al. 1997
Japan, serum	< 20	M	45	GM 63.8	24.6–156.6	Usuda et al. 1997
Japan, serum	20–29	M	45	GM 66.5	23.5–189.0	Usuda et al. 1997
Japan,	30–39	M	32	GM 75.2	27.7–166.3	Usuda et al.

Population	Age group	Sex	n	Mean ± SD µg/L	Range µg/L	Reference
serum						1997
Japan, serum	40–49	M	41	GM 86.5	33.7–210.2	Usuda et al. 1997
Japan, serum	50–59	M	71	GM 83.9	33.4–192.4	Usuda et al. 1997
Japan, serum	60–69	M	111	GM 85.1	31.8–237.8	Usuda et al. 1997
Japan, serum	70–79	M	38	GM 87.7	34.3–213.2	Usuda et al. 1997
Japan, serum	80+	M	14	GM 95.9	35.9–210.6	Usuda et al. 1997
Japan, serum	< 20–80+	M	397	GM 79.8	23.5–237.8	Usuda et al. 1997
Japan, serum	< 20	F	51	GM 59.4	19.6–151.6	Usuda et al. 1997
Japan, serum	20–29	F	104	GM 59.2	21.8–133.8	Usuda et al. 1997
Japan, serum	30–39	F	88	GM 63.0	25.2–181.6	Usuda et al. 1997
Japan, serum	40–49	F	93	GM 67.5	23.8–180.2	Usuda et al. 1997
Japan, serum	50–59	F	89	GM 72.1	25.3–187.5	Usuda et al. 1997
Japan, serum	60–69	F	87	GM 75.0	27.0–211.3	Usuda et al. 1997
Japan, serum	70–79	F	49	GM 82.0	35.9–134.9	Usuda et al. 1997
Japan, serum	80+	F	22	GM 82.4	43.9–169.9	Usuda et al. 1997

Abbreviations: SD, standard deviation; na, not available; GM, geometric mean.

Assumed blood density 1g/mL when converting weight/weight (wt/wt) to weight/volume (wt/vol).

**Table F-2: Blood boron concentrations in humans, high environmental exposure (µg/L)**

Population	Age group	Sex	n	Mean ± SD µg/L	Range µg/L	Reference
Northern Chile, whole blood	16–86	M+F	38	22–659 means by community	na	Barr et al. 1993
Northern Chile, siblings, plasma	na	na	19	253–901	na	Barr et al. 1996
Northern Chile, mothers 2–4 weeks after	28 (mean)	F	7	GM 430	210–1500	Harari et al. 2012

Population	Age group	Sex	n	Mean ± SD µg/L	Range µg/L	Reference
delivery, whole blood						
Northern Argentina, mothers 2–4 weeks after delivery, plasma	25 (mean)	F	24	GM 380	125–1360	Harari et al. 2012
Santiago control location, mothers 2–4 weeks after delivery, plasma	30 (mean)	F	11	GM 35	21–66	Harari et al. 2012

Abbreviations: SD, standard deviation; na, not available; GM, geometric mean. Assumed blood density 1g/mL when converting wt/wt to wt/v.

**Table F-3: Blood boron concentrations in human supplement studies (µg/L)**

Population	Age group	Sex	n	Mean ± SD µg/L	Range µg/L	Reference
11.6 mg dose plasma	45–65	M	15	0 hr 14 ± 10 4 hr 136 ± 20 6 hr 124 ± 20	na	Wallace et al. 2002
Placebo, plasma	45–65	M	15	8–16	na	Wallace et al. 2002
Peri-menopausal women, 2.5 mg dose plasma	Older adult	F	19	53 ± 12	28–75	Nielsen and Penland 1999
Peri-menopausal women, placebo, plasma	Older adult	F	24	34 ± 10	20–67	Nielsen and Penland 1999
Post-menopausal women, 3 mg dose plasma	48–82	F	11	95 ± 56		Hunt et al. 1997
Post-menopausal women, placebo, plasma	48–82	F	11	64 ± 45		Hunt et al. 1997
Weightlifters,	Adults	M	10	32.9 <sup>a</sup>	< 12–77	Green and

Population	Age group	Sex	n	Mean ± SD µg/L	Range µg/L	Reference
2.5 mg dose plasma						Ferrando 1994
Weightlifters, placebo, plasma	Adults	M	9	8.4	< 12–17	Green and Ferrando 1994

Abbreviations: SD, standard deviation; na, not available; GM, geometric mean.

Assumed blood density 1g/mL when converting wt/wt to wt/v.

<sup>a</sup> Used ½ LOD to calculate average blood concentration.

**Table F-4: Blood boron concentrations in human worker studies (µg/L)**

Population	Age group	Sex	n	Mean ± SD µg/L	Range µg/L	Reference
China, remote background community, control, serum	Adult	M	23	39.1	8.20–72.1	Scialli et al. 2010
China, local community, control (environmental exposure), serum	Adult	M	15	114	3.29–348	Scialli et al. 2010
China, workers, boron plant (occupational airborne and environmental exposure), serum	Adult	M	75	252	22.8–2482	Scialli et al. 2010
China, workers, Pengxiang plant (highest occupational airborne exposure and environmental exposure), serum	Adult	M	16	1558 ± 1041	na	Scialli et al. 2010
Turkey, workers,	26–52	M	49	< LOQ (< 48.5)	< LOQ	Duydu et al. 2011

<b>Population</b>	<b>Age group</b>	<b>Sex</b>	<b>n</b>	<b>Mean ± SD µg/L</b>	<b>Range µg/L</b>	<b>Reference</b>
control, whole blood						
Turkey, workers, low exposure, whole blood	23–50	M	72	72.94 +/- 15.43	48.46– 99.91	Duydu et al. 2011
Turkey, workers, medium exposure, whole blood	32–50	M	44	121.68 +/- 15.62	100.51 –146.01	Duydu et al. 2011
Turkey, workers, high exposure, whole blood	28–53	M	39	223.80 +/- 69.49	152.82– 152.82	Duydu et al. 2011

## Appendix G: Summary of Blood Boron Concentrations and Intake Concentrations in Various Human Exposure Studies

Exposure type	Mean intake (mg B/kg bw/d)	Mean blood concentration $\pm$ SD or (min-max) ( $\mu\text{g/L}$ )	Reference
Supplement study (placebo)	0.017 <sup>ac</sup>	34 $\pm$ 10	Nielsen and Penland 1999
Supplement	0.047 <sup>ac</sup>	53 $\pm$ 12	Nielsen and Penland 1999
Supplement study (placebo)	0.005 <sup>c</sup>	64 $\pm$ 45 <sup>e</sup>	Hunt et al. 1997
Supplement	0.049 <sup>c</sup>	95 $\pm$ 56 <sup>e</sup>	Hunt et al. 1997
Supplement	0.032 <sup>c</sup>	32.9 ( $\leq$ 12-77) <sup>f</sup>	Green and Ferrando 1994
Supplement	0.133 <sup>c</sup>	124 $\pm$ 20 <sup>g</sup>	Wallace et al. 2002
Drinking water (northern Chile)	0.010 <sup>a</sup>	22 $\pm$ 2 <sup>g</sup>	Barr et al. 1993
Drinking water	0.020 <sup>a</sup>	68 $\pm$ 34 <sup>g</sup>	Barr et al. 1993
Drinking water	0.040 <sup>a</sup>	52 $\pm$ 15 <sup>g</sup>	Barr et al. 1993
Drinking water	0.06 <sup>a</sup>	347 $\pm$ 163 <sup>g</sup>	Barr et al. 1993
Drinking water	0.24 <sup>a</sup>	585 $\pm$ 166 <sup>g</sup>	Barr et al. 1993
Drinking water	0.300 <sup>a</sup>	450 $\pm$ 87 <sup>g</sup>	Barr et al. 1993
Drinking water	0.39 <sup>a</sup>	659 $\pm$ 337 <sup>g</sup>	Barr et al. 1993
Drinking water, mother-infant (Argentina)	0.13 <sup>ad</sup>	GM 430 (210–1500)	Harari et al. 2012
Drinking water, mother-infant (northern Chile, Arica)	0.20 <sup>ad</sup>	GM 380 (125–1360)	Harari et al. 2012
Drinking water, mother-infant (Chile, capital [Santiago])	0.005 <sup>ad</sup>	GM 35 (21–66)	Harari et al. 2012
Worker study, China (remote control)	0.02 <sup>bh</sup>	39.1 (8.20–72.1)	Scialli et al. 2010
Worker study, China (2004 community control)	0.07 <sup>bh</sup>	114 (3.29–348)	Scialli et al. 2010

<sup>a</sup> Assumed to weigh 70 kg.

<sup>b</sup> Assumed to weigh 60 kg because the average body weight of Chinese cohorts is lower than the other cohorts.

<sup>c</sup> Intake estimates include dietary intakes.

<sup>d</sup> Assumed water consumption of 1.8L/day (as per Barr et al. 1993).

<sup>e</sup> Data presented in  $\mu\text{mol/L}$ : used molecular weight of boron as 10.8 g/mol to convert  $\mu\text{g/L}$ .

<sup>f</sup> Average was calculated based on individual plasma boron concentrations; half of the detection limit was assumed for data at  $\leq$  limit of detection.

<sup>g</sup> Assumed blood density of 1 kg/L when converting weight/weight to weight/volume.

<sup>h</sup> Boron exposure through environmental media (mainly diet and drinking water).

## Appendix H: Health Effects Data

Key animal study	Protocol	Result
90-day dietary, dog	<p>5/sex/dose, borax</p> <p>Dose levels in boron equivalents: 0.0, 0.4, 5.0, 46.2 mg B/kg bw/d</p>	<p>NOAEL (mg/kg bw/d): provisional ♀: 46.2, ♂: 5.0</p> <p>Results/effects:</p> <p>≥ 0.4 mg/kg bw: dose-related ↓ in abs+rel testis wt, but not seen in 2-yr dog at this dose level.</p> <p>≥ 5.0 mg/kg bw: all 5 ♂ had artifactual distortion of the tubules in the outer 1/3 of the gland. The ♂s also had a greater proportion of small and solid epithelial nests (thyroid) and ♀ adrenal cortex was distinctly widened (considered non-adverse).</p> <p>@ 46.2 mg/kg bw: severe testicular atrophy in all dogs, complete degeneration of the spermatogenic epithelium in 4/5 dogs, with partial degeneration in 1 ♂ (dog died on day 68, congestion of kidneys and small and large intestines), ↑ interstitial cells and Leydig-like cells. Abs testicular wt ↓ 40–44%, rel to bw and brain wt ↓.</p> <p><u>Liver, spleen, kidney</u>: hemosiderin pigment accumulation from the breakdown of RBC. Effect more severe in ♂, but number of animals affected not given.</p> <p>Supplemental (no ovary data, poor reporting of control data, no individual path. reports). No sperm analysis.</p> <p>(Study No. 1237735, cited in Health Canada 2012)</p>

<p>90-day dietary, dog</p>	<p>5/sex/dose, boric acid</p> <p>Dose levels in boron equivalents: 0.0, 0.46, 4.2, 35 mg B/kg bw/d; dose levels for ♂ calculated from actual test article intake and converted into boron equivalent intake.</p>	<p>NOAEL (mg/kg bw/d): provisional ♀: 35.0, ♂: 4.2</p> <p>Results/effects:</p> <p>≥ 4.2 mg/kg bw: ↓ in abs and rel (to body weight) testes wt, but not seen in 2-yr dog at this dose level, testes of all 5 ♂ had artifactual distortion of the tubules in the outer 1/3 of the gland. The ♂ had ↑ in small and solid epithelial thyroid nests (2 with squamous metaplasia).          @ 35 mg/kg bw: ↓ rel thyroid (♂). Severe testicular atrophy in all ♂s. Degeneration of the spermatogenic epithelium was generally complete except in one dog where some activity remained in 2/3 of tubules, ↑ in interstitial tissue. ♀: ↑ of lymphoid infiltration and atrophy of the thyroid.</p> <p>Supplemental (no ovary data, poor reporting of control data, no individual path. reports).</p> <p>No sperm analysis.</p> <p>(Study No. 1249382, cited in Health Canada 2012)</p>
<p>Teratology dietary feeding study, Sprague-Dawley rat, boric acid</p>	<p>Gestation day 0–20</p> <p>30/dose, teratogenic evaluation</p> <p>30/dose, postnatal evaluation</p> <p>Dose levels in boron equivalents: 0, 3.3, 6.3, 9.6, 13.3, 25.0 mg B/kg bw/d</p>	<p>Developmental NOAEL: 9.6 mg/kg bw/d (the conclusive developmental NOAEL that could not be set in the previous studies).</p> <p>No maternal toxicity: as in the previous CNS study, there were no maternal effects after correcting for gravid uterine wt: “No maternal deaths occurred and no distinctive treatment-related clinical signs of toxicity were observed during either study (this study and the original NTP developmental study).”</p> <p>Developmental:</p> <p><i>Phase I (teratogenic evaluation (gd 20))</i>          ≥ 9.6 mg/kg bw: ↑ in short rib XIII          ≥ 13.3 mg/kg bw: ↑ in wavy rib, ↓ in fetal BW  <i>Phase II (postnatal)</i>          There was recovery from the ↓ in fetal BW.          @ 25 mg/kg bw: ↑ in short rib XIII (postnatal day 21)</p> <p>Supplemental NTP study to support the 1990 NTP study.          Fetal and offspring sensitivity.</p> <p>(Cited in Health Canada 2012)</p>

Human study	Protocol	Result
Poisoning case / short-term study	Oral exposure (some source doses were not able to convert to boron-equivalent doses)	<p>Accidental single ingestion of approx. 5 g of sodium perborate bleach (95%) often led to vomiting, diarrhoea and abdominal pain (Kliegel 1980).</p> <p>In a case study of seven infants (aged 6–16 weeks at the end of the exposure) exposed to borax in a honey-borax mixture in their diet at 429–1287 mg/d (equivalent to 9.6–33 mg B/kg-bw/d, Taylor 1997) for 4–10 weeks, seizures, convulsions and other milder effects were observed.</p> <p>Early case reports have shown that death in newborns occurred within five days of ingesting less than 3 g of boric acid (Young et al. 1949).</p> <p>One 4.5-month-old infant who ingested (via pacifier dipped in honey and borax mixture) approx. 125 g borax over three months induced a seizure disorder (accumulated exposure); the tested blood boron level was 1.64 mg/100 mL (Gordon et al. 1973).</p> <p>The lowest lethal doses for humans exposed to boric acid were 640 mg/kg-bw by oral exposure, 8600 mg/kg-bw by dermal exposure, and 29 mg/kg-bw by intravenous injection (Stokinger 1981).</p> <p>The potential lethal doses in humans for boric acid reported by Litovitz et al. (1988) were 3–6 g total for infants and 15–20 g total for adults.</p> <p>Degenerative changes in parenchymal cells with oliguria and albuminuria were demonstrated in two newborn infants after ingestion of 505 and 765 mg B/kg-bw/d as boric acid in an evaporated milk formula over a period of 3–5 days. Five infants who ingested formula accidentally prepared with 2.5% aqueous solution of boric acid (no daily dose provided) became lethargic, developed vomiting and diarrhea, and died within three days of exposure (Wong et al. 1964).</p> <p>12 young male volunteers were dosed up to 870 mg B/d of boric acid or borax equivalent for 4 days –2 weeks, resulting in a loss of appetite, a feeling of fullness and uneasiness in the stomach, or</p>

		<p>nausea. Similar reversible adverse effects were observed at a diet-dose level of 0.5 g of B/d (87 mg B/day) for 50 days (Wiley 1904).</p> <p>Epilepsy patients receiving 5 or more mg B/kg bw/d (over two years [route unspecified]) developed dermatitis, alopecia and indigestion. When the dose was reduced to 2.5 mg B/kg bw/d, the signs and symptoms disappeared (Culver and Hubbard 1996).</p>
Poisoning case / short- term study	Dermal exposure (some source doses were not able to convert to boron-equivalent doses)	Accidental misuse in the preparation of baby formula (1–14 g boric acid in the formula) and the topical use of pure boric acid powder for infants has led to poisonings (Austria 2008a). Repeated dermal application of boric acid containing baby powder induced cutaneous lesions (erythema over the entire body, excoriation of the buttocks, and desquamation) gastrointestinal disturbances, and seizures (Goldbloom and Goldbloom 1953).
Eye and respiratory irritation	113 boron workers and 214 controls exposed to mean total level of 4.1 mg/m <sup>3</sup> boron oxide or 4.1 mg/m <sup>3</sup> boric acid (equivalent to 1.3 and 0.7 mg B/m <sup>3</sup> )	Boron exposure was significantly associated with respiratory symptoms and eye irritation (dryness of mouth, nose or throat; sore throat; and reproductive cough) (Garabrant et al. 1984). The follow-up study of 629 workers confirmed this finding. The author concluded that borax dust is an acute respiratory irritant at exposures of 4.4 mg/m <sup>3</sup> (0.6 mg B/m <sup>3</sup> or more), which is a level of respiratory irritation that produces chronic bronchitis without impairment of pulmonary function. At an exposure level of 4.0 mg/m <sup>3</sup> , eye irritation was noted in over 5% of participants (Garabrant et al. 1985).
Eye and respiratory irritation	Boron workers (number not defined) exposed to boron dust for 6h/day, at 5.72 mg/m <sup>3</sup> of total dust (equivalent to 0.44 mg B/m <sup>3</sup> , 1.0–10.0 mg/m <sup>3</sup> of total dust)	The acute irrigative effects and chronic pulmonary function analyses of the incidence and severity of irritant symptoms in boron workers indicated that exposure-response relationships were presented for each symptom. The exposure – response trends were statistically significant (p < 0.05), except for eye irritation (Wegman et al. 1991, 1994).
Respiratory irritation	12 subjects, exposed to 5, 10, 20, 30 and 40 mg/m <sup>3</sup> borax dust or 10 mg/m <sup>3</sup> boric acid dust for 20 min while performing moderate exercise.	Sensory perception was judged among subjects by level of feeling or irritation in the eye, nose and throat at 5-min intervals. At 10 mg/m <sup>3</sup> (1.5 mg B/m <sup>3</sup> borax or 1.75 mg B/m <sup>3</sup> boric acid), nasal secretion increased in participants (Cain et al. 2004, 2008).
Eye irritation	Sodium perborate (no protocol provided)	Sodium perborate induced reversible eye irritation, and irritative effects on the mucosa of the nose were reported in boron workers (Solvay 2002).

Skin irritation	Sodium perborate monohydrate, 26 volunteers (aged 18–65), 0.2 g sodium perborate on a 25 mm pad, from 15 min to 4 h.	0.2 g sodium perborate on a 25 mm pad was applied on the upper, outer arm of subjects progressively from 15 min to 4 h, in a sequential single-patch test. 1/26 tested volunteers showed a positive skin reaction, while 21/ 26 reacted to the positive control (sodium dodecyl sulfate). The material was evaluated as non-irritant to human skin (York et al. 1996).
Human epidemiological study		Several epidemiological studies investigated the potential impact of boron compounds on fertility and sperm quality in boron workers and a sub-population living in boron-rich areas of the United States, Turkey and China. However, due to the methodological deficiencies (small sample size for the population studied, unsuitable measurement means, improperly characterized exposure, and inconsistency in confounding adjustment), these studies were unable to confirm the absence of an effect in humans. The studies were reviewed in this assessment report; see text for details.