Government of Canada Gouvernement du Canada

Updated Draft Assessment

Boric Acid, its Salts and its Precursors

Environment and Climate Change Canada
Health Canada

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Canada

Synopsis

Pursuant to section 68 of the *Canadian Environmental Protection Act, 1999* (CEPA), the Minister of the Environment and the Minister of Health have conducted an assessment of boric acid, its salts and its precursors. The first draft screening assessment was published in July 2016. Significant new use and exposure information, including additional environmental monitoring and human biomonitoring data from the Canadian Health Measures Survey (CHMS), subsequently became available. As a result, the draft assessment was updated and is presented here.

This updated draft assessment focuses on boric acid, a common moiety of concern, and therefore considers boric acid, its salts and its precursors, including any boron-containing substance that may release boric acid through any transformation pathway (for example, hydrolytic, oxidative, or metabolic) at environmentally or physiologically relevant conditions (for example, pH and temperature). Boron-containing chemicals and associated hydrated forms were evaluated for their potential to be salts or precursors of boric acid. This assessment considers the total exposure of humans and other living organisms to boric acid, whether from environmental media (for example, water, sediment, soils, or air), food, or products available to consumers. The potential for cumulative effects was considered in this assessment by examining cumulative exposures to the moiety of boric acid.

Boric acid has both natural and anthropogenic sources. Natural sources of boric acid include sea-salt aerosols, soil dusts, volcanoes, biomass burning (for example, 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. Information submitted in response to a CEPA section 71 notice indicates that 9 boron-containing substances were manufactured or imported in Canada in quantities ranging from less than 0.1 tonnes to 1,000 tonnes and imported in quantities ranging from less than 1 tonne to 10,000 tonnes in 2008 and 2011. In addition, information from the Canadian International Merchandise Trade Database indicates that 54,810 tonnes to 65,795 tonnes of boric acid, its salts and its precursors were imported annually into Canada from 2017 to 2020, of which between 53,489 tonnes and 64,394 tonnes were used domestically.

Boric acid, its salts and its precursors are used in a wide variety of products and applications, including cellulose and fibreglass insulation manufacturing, industrial and consumer cleaning products, self-care products (that is, cosmetics, natural health products, and non-prescription drugs), other chemicals, gypsum board manufacturing, engineered wood products manufacturing, oil and gas extraction, agriculture (for example fertilizers), pulp and paper manufacturing and packaging, rubber manufacturing, chemical manufacturing, metallurgical applications, and surface finishing. Sectors identified as anthropogenic sources of boric acid include the incidental production and subsequent release of boric acid as a result of activities such as coal-fired power generation, metal ore 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, pulp and paper manufacturing, wastewater treatment (including the land application of biosolids), and waste disposal (landfill leachate). In addition, boric acid, its salts and its precursors are present in a number of products available to consumers and related uses, including arts and crafts materials and toys, do-it-yourself (DIY) products (including adhesives and sealants, automotive maintenance, home maintenance, and paints and coatings), flame retardant uses, and swimming pool and spa maintenance products.

Ecological exposure scenarios were developed for various activities that represent significant sources of releases of boric acid, its salts and its precursors to the environment, including: pulp and paper manufacturing, products available to consumers, rubber manufacturing, electroplating, fibreglass insulation manufacturing, cellulose insulation manufacturing, gypsum board manufacturing, engineered wood manufacturing, and fertilizer and pest control products manufacturing. In addition, exposure scenarios were developed for the following sectors on the basis of their potential to release boric acid incidentally (as a by-product): coal-fired power generation, metal ore mining, base and precious metals smelting and refining, coal mining, oil sands extraction and processing, and wastewater and waste management.

A metalloid ion like boric acid is considered to be infinitely persistent. Boron, absorbed as boric acid, is an essential micronutrient in most plants and some animals. Generally, boric acid is not considered to be bioaccumulative in most aquatic organisms, although bioaccumulation has been observed in some aquatic plants and algae. Evidence suggests that boric acid does not biomagnify in the environment.

The ecological effects assessment focused on the effects of boric acid in aquatic and soil-dwelling organisms. A long-term predicted no-effect concentration (PNEC) value of 1.5 mg B/L for aquatic organisms based on the Canadian Water Quality Guideline was derived from ecotoxicity studies using a species sensitivity distribution approach by the Canadian Council of Ministers of the Environment. Considering that anthropogenic boric acid added in soil is highly bioavailable compared with natural sources of boron, an added fraction of boric acid $\mathrm{PNEC}_{\mathrm{added}}$ was derived for soil-dwelling organisms.

A weight-of-evidence approach was used to determine the potential for ecological harm in Canada. Risk quotient analyses were performed by comparing predicted environmental concentrations with PNECs. The outcome of the ecological risk characterization indicates low potential for ecological harm from most sectors and activities that release boric acid. However, potential for ecological harm was identified as a result of aquatic releases of boric acid from one facility that processed recovered slags for precious and other base metals from the metal ore mining sector.

Considering all available lines of evidence presented in this updated draft assessment, there is risk of harm to 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.

People in Canada have background exposure to boric acid from its natural and anthropogenic presence in environmental media, food, and drinking water. As boron is considered to be an essential micronutrient for plant growth, naturally occurring boron in fruits and vegetables and, to a lesser extent, drinking water are the primary contributors to background exposure. Considering the universally recognized health benefits of diets rich in fruits and vegetables, background dietary exposure from natural sources is not considered to be of concern for the general population in Canada.

In addition, the general population in Canada is exposed to boric acid from a variety of uses and products. Population exposure to boron was characterized using urine biomonitoring data from the nationally representative CHMS and the First Nations Youth, Environment and Health study, as well as blood biomonitoring data from the Alberta Biomonitoring Program, the Northern Saskatchewan Prenatal Biomonitoring study, and several smaller studies conducted in Europe. Total boron measured in urine and blood provides a biologically relevant, integrated measure of exposure that may occur from all routes (for example, oral, dermal, and inhalation) and all sources (for example, including environmental media, food, and frequently or commonly used products). Generally, females were found to have higher urinary concentrations of boron than males, while males were found to have higher blood concentrations. There is a “U”-shaped age-related pattern in urinary boron concentrations across the population. Overall, young children have higher urinary boron concentrations than adults. Pregnancy status did not impact exposure levels. No differences in exposure were observed between Indigenous and non-Indigenous people living in Canada.

Biomonitoring data were considered to be the most appropriate data for estimating combined systemic exposure to boric acid from all routes and sources. Exposure estimates predicted from the urine biomonitoring data for the general population and for males aged 3 to 5 years of age from the CHMS were used to characterize risk to human health. Margins of exposure (MOEs) between the exposure estimates and the chronic critical health effect (decreased testicular weight) were considered potentially inadequate to address uncertainties in the health effects and exposure data used to characterize risk.

Exposure estimates were derived for uses and products in order to help identify sources of exposure. The exposure estimates indicate that there are many uses and products that contribute to exposure at levels that are similar to or well above background exposure from food, drinking water, and environmental media. MOEs between exposure estimates for some arts and crafts materials and toys, cleaning products, flame retardants, DIY products, self-care products (cosmetics, natural health products, and non-prescription drugs), and swimming pool and spa maintenance products, and the acute critical health effect (skeletal abnormalities) for infrequently or intermittently used products or the chronic critical health effect (decreased testicular weight) for frequent or daily use products are considered potentially inadequate to address uncertainties in the health effects and exposure data used to characterize risk.

In addition to systemic effects from exposure to boric acid, effects following inhalation exposure to boron trifluoride and boron trifluoride monoetherate were identified. The MOE between the estimated air concentration from use of cosmetic nail and eyelash adhesives and the critical health effect for boron trifluoride was considered adequate to address uncertainties in the health effects and exposure data used to characterize risk.

The human health assessment took into consideration those groups of individuals within the general population who, due to greater susceptibility or greater exposure, may be more vulnerable to experiencing adverse health effects. Males or people assigned male at birth of all ages were found to be more susceptible to adverse health effects of boric acid than pregnant women and pregnant people, the developing fetus, and children. Children were found to have higher exposure than adults. Higher urinary boron concentrations were associated with people who identified as White, had higher education levels, were normal weight or underweight, were non-smokers, or who had higher consumption of fruits and vegetables.

Considering all of the information presented in this updated draft assessment, 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.

It is therefore 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.

It is also proposed that boric acid, its salts and its precursors meet the persistence criteria but not the bioaccumulation criteria as set out in the *Persistence and Bioaccumulation Regulations* of CEPA.

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1. Introduction

Pursuant to section 68 of the *Canadian Environmental Protection Act, 1999* (CEPA) (Canada 1999), the Minister of the Environment and the Minister of Health have conducted an assessment of boric acid, its salts and its precursors, to determine whether these substances present or may present a risk to the environment or to human health.

This assessment focuses on the moiety boric acid and therefore considers boric acid, its salts and its precursors. As a result, this assessment considers boron-containing substances beyond those identified as priorities for assessment. A moiety approach was taken in order to assess the potential for cumulative effects from the boric acid moiety. It is recognized that the combined exposure of humans and other organisms to boric acid may occur through different pathways and sources. Exposure to boric acid may occur as a result of anthropogenic activities involving boron-containing substances as well as through incidental production. For the purposes of this updated draft assessment, “boric acid” refers to boric acid, its salts and its precursors. Where relevant, specific substances containing boron will be explicitly identified by name or its Chemical Abstracts Service Registry Number (CAS RN[1]). For ease of comparison of 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.

A non-exhaustive list of 126 boron-containing substances that are precursors or non-precursors of boric acid is available in Appendix A and consists of nineteen substances which were identified as priorities for assessment as they met categorization criteria or were prioritized through other mechanisms (ECCC, HC [modified 2017]). 6 additional substances on the *Revised In Commerce List* (R-ICL)[2] were included in this assessment (Health Canada [modified 2023a]).

The first draft screening assessment for boric acid, its salts and its precursors was published in July 2016 (ECCC, HC 2016). It proposed that boric acid, its salts and its precursors were harmful to the environment and to human health. Significant new use and exposure information, including additional environmental monitoring data for some industrial sectors (that is, metal ore mining, base metals and precious metals smelting and refining, pulp and paper, and wastewater systems) and human biomonitoring data from the Canadian Health Measures Survey (CHMS), subsequently became available. In addition, exposure estimates were derived for uses or products not included in the

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[1] The CAS RN is the property of the American Chemical Society, and any use or redistribution, except as required in supporting regulatory requirements and/or for reports to the Government of Canada when the information and the reports are required by law or administrative policy, is not permitted without the prior written permission of the American Chemical Society.

[2] The R-ICL is an administrative list of substances that are potentially used in products that are regulated under the *Food and Drugs Act* and that were in commerce in Canada between January 1, 1987 and September 13, 2001. The Government of Canada has prioritized these substances and is addressing them for their potential impact on human health and the environment in order to risk-manage them, if required.

first draft screening assessment to help identify sources of exposure (for example, flame retardants). On the basis of this information, an updated draft assessment is presented here.

This updated draft assessment includes the consideration of information on chemical properties, environmental fate, hazards, uses, and exposures, including additional information submitted by stakeholders. Relevant data were identified up to 2023 for both the human health and ecological components of this assessment. Key studies were critically evaluated and, along with the use of modelled results, were used to reach the proposed conclusions. When available and relevant, information presented in risk and hazard assessments from other jurisdictions was considered. This 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 relevant sections of this report (ECCC 2019, 2021a-h).

This updated draft assessment was prepared by staff in the CEPA Risk Assessment Program 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 consultation. Comments on the technical portions of the first draft screening assessment 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 of the first draft screening assessment relevant to the environment were received from Dr. Michael C. Harrass, consultant, Dr. Beverley Hale, University of Guelph, and Dr. Lawrence Kaputska, LK Consultancy. Additionally, the first draft screening assessment was subject to a 60-day public comment period. While external comments were taken into consideration, the final content and outcome of this updated draft assessment remain the responsibility of Health Canada and Environment and Climate Change Canada.

Assessments focus on information critical to determining whether substances meet the criteria as set out in section 64 of CEPA by considering scientific information, including, if available, information on subpopulations who may have greater susceptibility or greater exposure, vulnerable environments, and cumulative effects,[3] and by incorporating a weight-of-evidence approach and precaution.[4] This updated draft

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[3] The consideration of cumulative effects under CEPA may involve an analysis, characterization, and possible quantification of the combined risks to health or to the environment from exposure to multiple chemicals.

[4] 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 products available to consumers. A conclusion under CEPA is not relevant to, nor does it preclude, an assessment

assessment presents the critical information and considerations on which the proposed conclusions are based.

2. Identity of substances and scope of the assessment

This assessment focuses on a common moiety of concern, boric acid, and considers the combined exposure of humans and other organisms to boric acid from different pathways and sources.

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 (for example, hydrolytic, oxidative, or metabolic) at environmentally or physiologically relevant conditions (for example, pH and temperature); these are considered to be precursors of boric acid. Thus, this assessment focuses on boric acid, its salts and its precursors. Salts or 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 (for example, sodium borate silicates or borosilicate glass), which therefore fall outside the scope of this assessment. Boron-containing chemicals on the *Domestic Substances List* (DSL) and the R-ICL as well as any associated hydrated forms were evaluated for their potential to be precursors of boric acid (Environment Canada and Health Canada 2014) (see Appendix A, Table A-1 for a non-exhaustive list); however, the scope of this assessment is not limited to the non-exhaustive list of these substances in Appendix A. A non-exhaustive list of boron-containing chemicals found to be non-precursors is provided in Appendix A, Table A-2.

The presence of boric acid in environmental media, food, or products may result from natural or anthropogenic sources. Anthropogenic sources of boric acid include the incidental production and release (that is, as a by-product) of boric acid, its salts and its precursors as well as the import and use of these substances and products or manufactured items containing these substances. 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 (that is, 17.5%) of the mass of boric acid on a molecular weight basis. Substances that are salts or precursors of boric acid under environmentally and physiologically relevant conditions and concentrations are considered to be toxicologically equivalent to boric acid. Therefore, concentrations and doses of boric acid reported in this assessment are

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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 that is based on the criteria contained in section 64 of CEPA does not preclude actions being taken under other sections of CEPA or other acts.

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 considers the 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). Some of these other elements or moieties have been addressed through previous assessments conducted as part of the *Priority Substances List* program under CEPA or may be addressed via other initiatives of the Chemicals Management Plan (CMP).

Engineered nanomaterials containing boron that may be present in environmental media or in products are not explicitly considered in the exposure scenarios of this updated draft assessment, but measured concentrations of boron in the environment or human biomonitoring data could include boron from these sources. Similarly, this updated draft assessment does not explicitly consider ecological or health effects associated with nanomaterials containing boron. The Government of Canada's Proposed Approach to Address Existing Nanomaterials will consider nanoscale forms of substances currently on the DSL (ECCC, HC [modified 2023]).

3. 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 Brönsted-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 (less than or equal to 0.025M, or approximately 0.27 g B/L) (IPCS 1998), which encompass the environmentally and physiologically likely range, boric acid is in equilibrium with the borate anion ($B(OH)_4^-$). However, on the basis of the acid dissociation constant (pK_a) value of 9.0 at 25°C, boric acid will exist predominantly in its neutral, undissociated form at environmentally and physiologically relevant pH values (for example, 5 to 8).

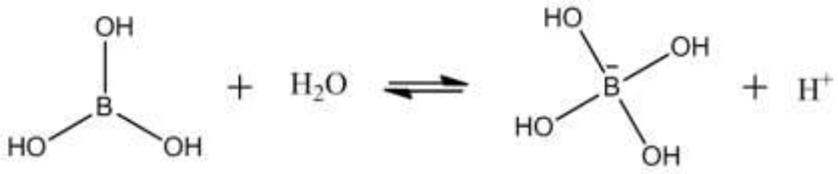

Figure 3-1. Aqueous equilibrium of boric acid with the borate anion ($B(OH)_4^-$), pK_a = 9.0 at 25°C

[Figure 3-1 displays the equilibrium of boric acid [$B(OH)_3$], which acts as a weak Lewis acid, with the borate anion [$B(OH)_4^-$] in water. Based on its pK_a value of 9.0 at 25°C, boric acid will exist predominantly in its neutral, undissociated form at environmentally and physiologically relevant pH values (5 to 8).]

Physical and chemical properties play an important role in determining the environmental fate of substances as well as their effects on humans and non-human organisms.

Properties such as water solubility and acid dissociation constant (K_a) (Table 3-1) are particularly relevant to the environmental fate and ecotoxicity of boric acid, 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 (*temperature*)**	**Representative value (*temperature*)**	**Key reference(s)**
Physical state	NA	White odourless crystalline solid	Borax Europe 2012
Density (kg/m^3)	1,435 to 1,510 (*15 to 23^{o}C*)	1490 (*23^{o}C*)	IPCS 1998; Borax Europe 2012; ECHA 2007-2014;
Vapour pressure (Pa)	Generally considered negligible	9.9×10^{-5}	Borax Europe 2012
Water solubility (g/L)	47.2 to 63.5 (*20 to 30^{o}C*)	49.2 (*25^{o}C*)	IPCS 1998; ATSDR 2010; Borax Europe 2012; ECHA 2007-2014
Log K_{ow} (dimensionless)	-1.09 to (-)0.757	-1.09 (*22^{o}C*)	Borax Europe 2012; ECHA 2007-2014
pK_a (dimensionless)	8.94 to 9.42 (*20 to 25^{o}C*)	9.2 (*25^{o}C*)	IPCS 1998; ATSDR 2010; Borax Europe 2012; ECHA 2007-2014

Abbreviations: NA, not available; K_{ow}, octanol–water partition coefficient; pK_a, acid dissociation constant

Boric acid is considered highly soluble in water, with an extremely low log K_{ow} (Table 3-1). Pure boric acid is not volatile, as indicated by its low vapour pressure (9.9×10^{-5} Pa). However, boric acid can be volatilized with steam from heated aqueous solutions (owing to its dissolution into steam) or sublimed by high temperature processes (Schubert and Brotherton 2006; Ball et al. 2012). When heated, boric acid releases water in a stepwise fashion, forming various phases of metaboric acid (HBO_2) as temperature increases, and eventually forming boron oxide (B_2O_3) (Cotton and Wilkinson 1999). Gaseous metaboric acid species are formed by the equilibration of water vapour with molten boron oxide at 600°C to 1,000°C (Schubert and Brotherton 2006).

4. Sources and uses

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 found naturally 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 as cited in Parks and Edwards 2005). The average concentration of boron in ocean water has been reported to be 4.5 mg B/L. Borate aerosols formed in the atmosphere via the co-evaporation of boric acid with seawater, or the intrusion of seawater into fresh waters, may be a significant source of boron in coastal areas (Argust 1998; Jahiruddin et al. 1998; Parks and Edwards 2005).

Global natural atmospheric emissions of boron have been estimated to range between 1.1×10^9 kg B/year and 3.1×10^9 kg B/year (Park and Schlesinger 2002). The main sources include sea-salt aerosols, soil dusts, volcanoes, biomass burning (for example, 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 0.19×10^9 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 of these media.

4.2 Anthropogenic sources

4.2.1 Production

There are no commercially valuable deposits of boron-containing minerals in Canada. The majority of industrially important borates are sourced from the sodium borate minerals tincal and kernite, the calcium borate mineral colemanite, and the sodium-calcium borate mineral ulexite (USGS 2018). The largest global producers of borates in 2019 were the United States (US) and Turkey, followed by Chile, China, Bolivia, Germany, Peru, Russia, and Argentina (USGS 2021). There was no reported production of boron-containing minerals in Canada in 2018 (NRCan [modified 2021]). Furthermore, no evidence of the refinement of boron-containing minerals to other boric acid salts or precursors was identified in Canada.

4.2.2 Manufacture and imports

Information regarding the manufacture and import of boric acid, its salts and its precursors in Canada was acquired through surveys issued pursuant to section 71 of CEPA, data obtained from the Canada Border Services Agency (CBSA), data obtained from the Canadian International Merchandise Trade Database (CIMT), and from voluntary data submissions received from stakeholders. 13 substances were included in surveys issued pursuant to section 71 of CEPA for the reporting years of 2008, 2011, and 2012 to 2015 (Canada 2009, 2012, 2017). Table 4-1 presents a summary of the reported total manufacture and total import quantities for the surveyed boric acid, its salts and its precursors.

Table 4-1. Summary of information on Canadian manufacturing and imports of boric acid, its salts and its precursors submitted in response to CEPA section 71 surveys

CAS RN	Chemical name	Total manufactured (tonnes)[a]	Total imported (tonnes)[a]	Reporting year
10043-35-3	Boric acid	100 to 1,000	1,000 to 10,000	2008
11113-50-1	Boric acid	NR	10 to 100	2008
1303-86-2	Boron oxide	100 to 1,000	100 to 1,000	2008
10332-33-9	Sodium perborate monohydrate	NR	10 to 100	2011
1330-43-4	Sodium tetraborate	1 to 10	100 to 10,000	2008
1303-96-4	Borax	10 to 100	100 to 10,000	2008
12767-90-7	Zinc borate	NR	1 to 10	2008
1332-07-6	Zinc borate	NR	10 to 1,000	2008
68457-13-6	Cobalt boron neodeconate	0.1 to 1	10 to 100	2008
13840-56-7	Sodium orthoborate	NR	NR	2008
13814-96-5	Lead fluoroborate	NR	NR	2011
13826-83-0	Ammonium fluoroborate	NR	NR	2011
7637-07-2	Boron trifluoride	NR	NR	2012 to 2015

Abbreviation: NR, not reported above the reporting threshold of 100 kg per year

[a] Values reflect quantities reported in response to CEPA section 71 surveys (Environment Canada 2009a, 2013a). See surveys for specific inclusions and exclusions (Schedules 2 and 3).

Information on the import activities of boric acid, its salts and its precursors captured within Harmonized System (HS) codes for the years 2009 to 2012 on a company-by-company basis was obtained from the CBSA (2013). 12 HS codes (10-digit) corresponding to boric acid, its salts and its precursors were identified (Table 4-2). High-level aggregation of the quantity of boric acid, its salts and its precursors imported into Canada from 2009 to 2012 was tallied (Table 4-2) (CBSA 2013). Results indicate that the categories “oxides of boron and boric acid” and “disodium tetraborate – other hydrates” represented 70% to 91.5% of boric acid imported into Canada from 2009 to 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, on the basis of information submitted in response to a CEPA section 71 survey for the reporting year of 2008 and information on uses worldwide, quantities of boron oxide in commerce are much lower than quantities of boric acid (Environment Canada 2009a; Ball et al. 2012). The total import quantities recorded by the CBSA were assumed to correspond to boric acid for the purposes of calculating boron equivalents, given that compounds of most commercial importance (for example, borax pentahydrate, CAS RN 12179-04-3, and borax decahydrate, CAS RN 1303-96-4) as well as other boric acids, its salts and its precursors that corresponded to the HS codes have boron contents comparable to or lower than that of boric acid. This approach simplifies the exposure characterization and is also a conservative assumption. On the basis of this assumption, approximately 42,000 to 61,000 tonnes of boric acid were imported annually into Canada from 2009 to 2012.

Table 4-2. Annual aggregate quantities of boric acid imported into Canada from 2009 to 2012 (CBSA 2013)

HS code name[a]	HS code numbers	Quantity (tonnes) imported per year
Natural borates and concentrates	2528000000, 2528100000, 2528900000	1,500 to 13,000
Oxides of boron and boric acid	2810000000, 2810000010, 2810000020	6,000 to 25,000
Disodium tetraborate - anhydrous	2840110000	400 to 650
Disodium tetraborate – other hydrates	2840190000	26,000 to 31,000
Other borates, peroxo-borates of metals	2840200000, 2840300090	1,500 to 4,500
Peroxo-borate (perborates)	2840300000, 2840300010	50 to 200
Total[b]	**All relevant HS codes**	**42,000 to 61,000**

[a] 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.

[b] The quantities reported originate from multiple substances that may contain variable amounts of boron (5% to 31%) on the basis of their chemical formula.

Import and export quantities from the CIMT were considered to identify quantities imported into and exported from Canada in recent years. Import quantities and import quantities used domestically (that is, import quantities minus re-export quantities) of 6 HS codes corresponding to boron or boric acid (listed in Table 4-3) from 2017 to 2020 were considered (Statistics Canada [modified 2021]). Similarly to the CBSA data, it was assumed that the total import and export quantities reported in the CIMT for all 6 HS codes correspond to boric acid, its salts or its precursors for the purposes of calculating boron equivalents, thus simplifying the exposure characterization. From 2017 to 2020, Canada imported approximately 54,810 to 65,795 tonnes of boric acid per year, of which 53,489 to 64,384 tonnes were used domestically (Table 4-3) (Statistics Canada [modified 2021]).

Table 4-3. Summary of annual quantities of boron-containing commodities imported and import quantities used domestically (that is, import quantities minus re-export quantities) in Canada from 2017 to 2020 (Statistics Canada [modified 2021])

HS code name[a]	HS code	Quantity (tonnes) imported per year	Quantity (tonnes) used domestically
Natural borates and concentrates	252800	3,123 to 4,215	2,874 to 4,155
Oxides of boron and boric acids	281000	11,367 to 14,156	10,366 to 13,572
Disodium tetraborate – anhydrous	284011	368 to 2,748	334 to 2,731
Disodium tetraborate – other hydrates	284019	32,703 to 44,328	32,613 to 44,220
Other borates, peroxo-borates of metals	284020	3,097 to 4,900	3,096 to 4,875
Peroxo-borates (perborates)	284030	92 to 222	92 to 222
Total[b]	**All relevant HS codes**	54,810 to 65,795	53,489 to 64,384

[a] 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.

[b] The quantities reported originate from multiple substances that may contain variable amounts of boron (5% to 31%) on the basis of their chemical formula.

For the purposes 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 uses of other substances, mixtures, or products (NPRI 2022). Therefore, sectors that may incidentally produce boric acid as a result of their activities and generate releases to the environment are considered in this assessment.

Information regarding the incidental manufacture of boric acid was also acquired through a survey issued pursuant to section 71 of CEPA (Canada 2009). Results of this survey identified a number of coal-fired power generation stations 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 (that is, air, water, soil, or sediment): coal-fired power generation, metal ore 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 ECCC (2021b, 2021c, 2021d, 2021e, 2021f, 2021g). 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 7.3) for the sectors with the greatest expected releases of boric acid.

4.2.3 Uses

In Canada, the major uses of boric acid, and the sectors where use occurs, were identified using information submitted in response to surveys issued pursuant to section 71 of CEPA for the reporting years of 2008, 2011, and 2012 to 2015 (Canada 2009, 2012, 2017) as well as from CBSA import data for 2009 to 2012 (CBSA 2013), data gathering initiatives (ToxEcology Environmental Consulting Ltd. 2012, 2014; Cheminfo Services Inc., 2013a, 2013b, 2013c; EHS 2013;), and other stakeholder engagement activities. Importers identified through the CBSA were attributed to a sector on the basis of publicly available information regarding the Importer’s primary activity or by correlating the company’s activity with information submitted in response to CEPA section 71 surveys and voluntary stakeholder engagement. The data indicate that the major uses and sectors implicated in Canada include cellulose and fibreglass insulation manufacturing, industrial and consumer cleaning products, self-care products (that is, cosmetics, natural health products, and non-prescription drugs), other chemicals (for example, water softeners and swimming pool chemicals), gypsum board manufacturing, engineered wood products manufacturing, oil and gas extraction (for example, hydraulic fracturing fluids), agriculture (for example, fertilizers), pulp and paper manufacturing and packaging, rubber manufacturing, chemical manufacturing (for example, lubricants), metallurgical applications (for example, slag stabilization and analytical chemicals), and surface finishing (for example, the cleaner and buffer in electroplating). Further details are available in ECCC (2021a). In addition, publicly available websites and safety data sheets were used to identify products available to consumers, including arts and crafts materials and toys, do-it-yourself (DIY) products (including adhesives and sealants, automotive maintenance, home maintenance, paints and coatings), flame retardant uses, and swimming pool and spa maintenance products.

Additional information on the uses of boric acid, its salts and its precursors is presented in Tables 4-4 and 4-5 below.

Table 4-4. Summary of Canadian uses for boric acid, its salts and its precursors[a] in products available to consumers

Product category	Types of products	CAS RNs	Common names
Adhesive and sealant	Adhesive in paperboard, glue, plastic bonding, sealant, tape	10043-35-3, 11113-50-1, 1303-86-2, 1303-96-4, 1332-07-6, 4138265-88-0, 121-43-7, 109-63-7, 7637-07-2	boric acid, boric acid, boron oxide, borax, zinc borate, zinc borate, trimethyl borate, boron fluoride monoetherate, boron trifluoride
Arts and crafts materials and toys[b]	Glue, modelling clay, markers, melting figures, slimes and putties	10043-35-3, 11113-50-1, 1303-86-2, 1330-43-4, 12179-04-3, 1303-96-4	boric acid, boric acid, boron oxide, sodium tetraborate, borax pentahydrate, borax
Automotive maintenance	Antifreeze, body filler and repair, brake fluid, cleaning spray, coolant, crank fluid, de-icer, fuel additives, lubricants, polish, power steering fluid, radiator fluid, radiator sealant, tire mounting paste	10043-35-3, 11113-50-1, 1330-43-4, 7775-19-1, 10555-76-7, 12179-04-3, 1303-96-4, 26038-87-9, 26038-90-4, 14075-53-7, 93924-91-5	boric acid, boric acid, sodium tetraborate, sodium borate, sodium metaborate tetrahydrate, borax pentahydrate, borax, MEA-borate, MIPA-borate, potassium fluoroborate, UVCB
Building and construction materials	Cellulose insulation, fibreglass insulation, flame retardant, gypsum board, plywood, pressed panels, veneer sheets	10043-35-3, 11113-50-1, 1303-96-4, 12179-04-3, 12767-90-7, 1332-07-6, 138265-88-0, 149749-62-2, 12007-89-5, 12229-12-8, 12280-03-4	boric acid, boric acid, borax, borax pentahydrate, zinc borate, zinc borate, zinc borate, zinc borate, ammonium pentaborate, ammonium pentaborate tetrahydrate, disodium octaborate tetrahydrate

Product category	**Types of products**	**CAS RNs**	**Common names**
Cleaning products	Air freshener, abrasive powder, general purpose cleaner, carpet spot remover, floor cleaner, dishwashing detergent, laundry detergent and pre-wash spot remover, metal polish, toilet cleaner	10043-35-3, 11113-50-1, 11138-47-9, 10332-33-9, 10486-00-7, 7632-04-4, 13840-56-7, 1333-73-9, 7775-19-1, 1330-43-4, 1303-96-4, 12007-89-5, 12008-41-2, 68130-12-1, 10377-81-8	boric acid, boric acid, perboric acid sodium salt, sodium perborate monohydrate, sodium perborate tetrahydrate, sodium perborate, sodium orthoborate, boric acid sodium salt, sodium borate, sodium tetraborate, borax, ammonium pentaborate disodium octaborate, MEA-borate, MEA-borate
Home maintenance	Abrasive paper, drain cleaners, ice melt, nail hole filler, rust out solder paste, spackling, wood cleaner	10043-35-4, 1303-86-2, 7775-19-1, 1303-96-4, 13814-97-6, 13826-83-0, 14075-53-7, 16872-11-0	boric acid, boron oxide, sodium borate, borax, tin fluoroborate, ammonium fluoroborate, potassium fluoroborate, fluoroboric acid
Electrical and electronics	Lithium ion batteries, smoke and carbon monoxide detectors, TV and computer monitors	11113-50-1, 1303-86-2	boric acid, boron oxide
Flame retardant	Carpet backing, cellulose insulation, batting and textiles used in furniture, building materials, futons and mattresses, floor tiles, nylon, paper and paperboard, plastics and rubber, silicones, textiles (flame retardant clothing, sleepwear), wall coverings, wood	10043-35-3, 11113-50-1, 1330-43-4, 1303-96-4, 12767-90-7, 1332-07-6, 138265-88-0, 149749-62-2, 12007-89-5, 12229-12-8, 12280-03-4	boric acid, boric acid, sodium tetraborate, borax, zinc borate, zinc borate, zinc borate, zinc borate, ammonium pentaborate, ammonium pentaborate tetrahydrate, disodium octaborate tetrahydrate

Product category	Types of products	CAS RNs	Common names
	products, wire and cable		
Paints and coatings	Rust paint or as a buffer, coating additive, corrosion inhibitor, flame retardant	1303-86-2, 13701-59-2, 1330-43-4, 1303-96-4, 68457-13-6, 1332-07-6	boron oxide, barium borate, sodium tetraborate, borax, cobalt boron neodeconate, zinc borate
Water treatment	Chlorine treatments[c], swimming pool and spa maintenance products (clarifiers and pH balancers)	10043-35-3, 11113-50-1, 12179-04-3, 1303-96-4, 68457-13-6	boric acid, boric acid, borax pentahydrate, borax, cobalt boron neodeconate
Other	Cat litter, glass and ceramic, paper and paperboard	10043-35-4, 1303-86-2, 1330-43-4, 12179-04-3	boric acid, boron oxide, sodium tetraborate, borax pentahydrate

[a] Information submitted in response to CEPA section 71 surveys (Environment Canada 2009a, 2013a), data gathering initiatives (ToxEcology Environmental Consulting Ltd. 2012, 2014; Cheminfo Services Inc. 2013a, 2013b, 2013c; EHS 2013), and searches of publicly available data including safety data sheets (SDS Search Tool 2019).

[b] Under section 22 of the *Toys Regulations* of the *Canada Consumer Product Safety Act*, a toy must not contain boric acid or salts of boric acid if they could, under reasonably foreseeable circumstances, become accessible to a child or, if they are used as a filling, or could be released upon breakage or leakage (Canada 2011). In June 2023, Health Canada published a notice of intent to amend the *Toys Regulations* relating to boric acid and salts of boric acid (Health Canada [modified 2023b]).

[c] Algaecides and sanitizer pool products containing boron (as a formulant) are regulated under the *Pest Control Products Act* (Canada 2002).

Table 4-5. Additional uses for boric acid, its salts and its precursors in Canada

Use	Types of products	CAS RNs	Common names
Food additive	N/A	N/A	N/A
Incidental additive [a]	Additive in ethylene-vinyl acetate-vinyl alcohol copolymers and poly(ethylene/methacrylic acid) resin as a component of alkyd systems (level of less than 7.5%) and epoxy primers (level of less than 23%) in coatings for food plants on non-food contact surfaces	N/A	N/A

Use	Types of products	CAS RNs	Common names
Food packaging materials[b]	Component of adhesives, paper and paperboard food packaging materials, and in flocculants/retention aids that are used in the production of paper	N/A	N/A
Medicinal or non-medicinal ingredients in disinfectant, human, or veterinary drug products[c]	Medicinal and non-medicinal ingredient in non-prescription drug products. Non-medicinal ingredient in prescription drugs. Non-medicinal ingredient in otic and ophthalmic products, contact lens disinfectant, anti-bacterial hand cleaner, domestic and commercial disinfectants sunscreens. Medicinal ingredient in veterinary drugs.	10043-35-3, 1303-96-4	boric acid, borax (sodium borate in DPD [modified 2023])
Medicinal or non-medicinal ingredients in natural health products[d]	Medicinal ingredient in homeopathic and traditional Chinese medicines, joint health products, multi-vitamin/mineral supplements, oral health products, vaginal yeast infection products, and workout supplements. Non-medicinal ingredient in ophthalmic products, oral health products, topical creams and ointments.	7440-42-8, 10043-35-3, 1330-43-4, 1303-96-4, 7632-04-4, 1319-33-1, 250141-42-5 5743-34-0	boron (source ingredients as outlined in the NHPID include borax, boric acid, boron aspartate, boron citrate, boron-enriched yeast, boron glycinate, boron hydrolyzed animal protein (HAP) chelate, boron hydrolyzed vegetable protein (HVP) chelate, calcium borate, calcium borogluconate, calcium fructoborate, concentrated desalinated inland sea water, lignite, magnesium borate,

Use	Types of products	CAS RNs	Common names
			ocean mineral concentrate, seawater, sodium borate, and water), boric acid,[e] sodium tetraborate (called sodium borate in NHPID),[e] borax,[e] sodium perborate,[f] ulexite, calcium fructoborate
Notified to be present in cosmetics under the *Cosmetic Regulations*[g]	Bath products, hair care and colour products, lotions and moisturizers, makeup, massage oil, nail products, oral care products, skin care products, soaps and cleansers	10043-35-3, 11113-50-1, 1303-86-2, 11138-47-9, 7632-04-4, 7775-19-1, 1330-43-4, 12179-04-3, 1303-96-4, 1332-07-6, 68130-12-1, 10377-81-8, 26038-90-4, 68003-13-4, 7637-07-2, 109-63-7, 16940-66-2	boric acid, boric acid, boron oxide, perboric acid sodium salt, sodium perborate, sodium borate, sodium tetraborate, borax pentahydrate, borax, zinc borate, MEA-borate, MEA-borate, MIPA-borate, MIPA-borate, boron trifluoride, boron trifluoride monoetherate, sodium borohydride, boron citrate
Included on the List of Prohibited and Restricted Cosmetic Ingredients for Boric acid and its salts[h]	Cosmetics	10043-35-3, 11113-50-1, 7775-19-1, 1330-43-4, 1303-96-4, 1332-07-6, 10377-81-8, 68130-12-1, 26038-90-4, 68003-13-4, 7632-04-4, 1303-86-2, 11138-47-9, 12179-04-3	boric acid, boric acid, sodium borate, sodium tetraborate, borax, zinc borate, MEA borate, MEA borate, MIPA borate, MIPA borate, sodium perborate, boron oxide, perboric acid, sodium salt,

Use	Types of products	CAS RNs	Common names
			sodium tetraborate pentahydrate
Active ingredient in registered pest control products[i]	Insecticide and fungicide for structural, outdoor residential, enclosed bait stations, wood treatment, and material preservative uses	10043-35-3, 12179-04-3, 1303-96-4, 12447-61-9, 12280-03-4 2665-13-6 14697-50-8	boric acid, borax pentahydrate, borax, zinc borate, disodium octaborate tetrahydrate, tributyleneglycol biborate, hexyleneglycol biborate
Formulant in registered pest control products[j]	Component in algaecide and sanitizer pool products	7440-42-8 10043-35-3 11113-50-1, 1330-43-4, 12179-04-3, 1303-96-4	boron, boric acid, boric acid, sodium tetraborate, borax pentahydrate, borax
Fertilizer[k]	Plant micronutrient	10043-35-3, 11113-50-1, 1330-43-4, 12045-88-4, 12179-04-3, 1303-96-4, 12280-03-4, 1319-33-1, 10377-81-8	boric acid, boric acid, sodium tetraborate, borax pentahydrate, borax pentahydrate, borax, disodium octaborate tetrahydrate, ulexite, MEA-borate, calcium borate

Abbreviations: N/A, not applicable; NHPID, Natural Health Products Ingredients Database; Y = use was reported for this substance; N = use was not reported for this substance

[a] While not defined under the *Food and Drugs Act*, incidental additives may be regarded, for administrative purposes, as those substances which are used in food processing plants and which may potentially become adventitious residues in foods (for example, cleaners, sanitizers). Personal communication, email from the Food Directorate, Health Canada, to the Existing Substances Risk Assessment Bureau, Health Canada, 2022; unreferenced.

[b] Personal communication, email from the Food Directorate, Health Canada, to the Risk Management Bureau, Health Canada, 2013; unreferenced.

[c] Drug Product Database (DPD) [modified 2023]. Personal communication, email from the Therapeutic Products Directorate, Health Canada, to the Existing Substances Risk Assessment Bureau, Health Canada, dated February 14, 2020; unreferenced. Under the *Food and Drug Regulations* (Part C, Drugs, subsection C.01.028(1)(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 3 years of age (Canada 1978).

[d] Personal communication, email from the Natural and Non-prescription Health Products Directorate, Health Canada, to the Existing Substances Risk Assessment Bureau, Health Canada, dated February 5, 2020; unreferenced. Licensed Natural Health Products Database (LNHPD [modified 2023]) and Natural Health Products Ingredients Database (NHPID [modified 2023]). Source materials for multi-vitamin/mineral supplements and joint health products are outlined in the product monographs for multi-vitamin/mineral supplements (Health Canada 2018a, 2023c) and multiple ingredient joint health products (Health Canada 2019, 2022b).

[e] When included in topical natural health products, this ingredient must be used in accordance with the restrictions set out on the Hotlist, unless additional evidence for safety is submitted. Included in the Hotlist for this ingredient under "Restrictions" are (1) the risk statement "Do not use on broken or abraded skin" (required on the PLA [Product Licence Application)] form and label), (2) a subpopulation of "children over 3 years of age", and (3) a maximum concentration of 5% (NHPID [modified 2023]).

[f] The fact that this ingredient is restricted on the List of Prohibited and Restricted Cosmetic Ingredients (the Cosmetic Ingredient Hotlist) indicates that there are potential safety issues. This ingredient must be used in accordance with the restrictions set out on the Hotlist when included in natural health products, unless additional evidence for safety is submitted (NHPID [modified 2023]).

[g] Personal communication, email from the Consumer and Hazardous Products Safety Directorate, Health Canada, to the Existing Substances Risk Assessment Bureau, Health Canada, dated February 14, 2020; unreferenced

[h] Included on the List of Restricted Cosmetic Ingredients (more commonly referred to as the Cosmetic Ingredient Hotlist or simply the Hotlist), which is 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* (Health Canada [modified 2022a]). When used as a pH adjuster, the maximum permitted concentration is 0.1%. In other cosmetics, the maximum permitted concentration is 5% for boric acid and its salts, and warning and cautionary statements (to the effect of) "Do not use on broken or abraded skin, not to be used by children under 3 years of age." are required. Other boric acid precursors are described in other Hotlist entries: phenyl mercuric borate is described as prohibited in cosmetics; and sodium perborate, a peroxide-generating compound, is also subject to data submission and cautionary label statements associated with peroxide-generating compounds when used in oral products.

[i] Health Canada 2012, 2016

[j] Health Canada 2017a

[k] Boron is a recognized plant micronutrient under the *Fertilizers Regulations* (Canada 2020). There are approximately 100 micronutrient fertilizer products containing boron in Canada (CFIA [modified 2023a]).

5. Releases to the environment

5.1 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). Anthropogenic sources of boric acid, its salts and its precursors to air include the combustion of fossil fuels (especially coal), the manufacture of fibreglass and glass, and some mining and metallurgical processes (Temple et al. 1978; Eriksson et al. 1981; van Limpt 2007; Sakata et al. 2010; Environment Canada 2013b; Goodarzi 2013). Emissions of boric acid to air generally occur as gaseous and particulate forms of boron oxide, metaboric acid, or boron halides that further transform into boric acid (Park and Schlesinger 2002; van Limpt 2007; Environment Canada 2009a). Windblown particulate matter (PM) from dry tailings (from coal mining or oil sands extraction and processing) or ash piles from coal combustion may also be a potential atmospheric source of boric acid (ECCC 2021b, 2021e, 2021f).

5.2 Releases to water and sediments

Releases of boric acid to water may include (but are not limited to) releases from coal-fired power generation stations (ash ponds and power station 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 systems[5] (effluent) and landfills (leachate), metal ore mining and base metals smelters (effluents), agricultural run-off to surface waters, surface finishing (effluent), rubber products manufacturing (effluent), and building products manufacturing (for example, effluent from gypsum board, fibreglass insulation, and wood products manufacturing facilities) (ECCC 2021a, 2021b, 2021c, 2021d, 2021e, 2021f, 2021g, 2021h).

5.3 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.

6. Environmental fate and behaviour

6.1 Environmental distribution

6.1.1 Air

Owing to its negligible vapour pressure, boric acid 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 that the dominant chemical form is boric acid. Residence times of 19 to 36 days for gaseous boric acid and 2 to 6 days for particulate boric acid, respectively, were calculated. A second study conducted by Anderson et al. (1994) using a similar sampling protocol also found high percentages of gaseous boric acid in the atmosphere relative to particulate boric acid. The 2 sampling techniques involved the use of potassium hydroxide-impregnated cellulose filters to capture smaller particles, molecular aggregates, and gases collectively referred to as gaseous boric acid. Since the size of suspended particles in the atmosphere ranges from approximately 0.002 to 100 microns (µm) (Baird 1999), these studies may have overestimated the percentage of gaseous boric acid compared with the percentage of boric acid adsorbed to suspended particles or dissolved in atmospheric condensed phases. Flue gas measurements were taken in a full-scale coal combustion process equipped with selective catalytic reduction, electrostatic precipitation, and flue-gas desulphurization systems and showed boron concentrations in vapour phase that were comparable (that is, within one order of magnitude) to those of particulate phases prior to reaching pollution control systems (Cheng et al. 2009). It is expected that gaseous-phase boric acid and particulate boric acid emitted to the atmosphere will travel for a certain distance but that it will be removed from the atmosphere and deposited to

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[5] In this updated draft assessment, the term “wastewater 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 system makes no distinction of ownership or operator type (municipal, provincial, federal, indigenous, private, or partnerships). Systems located at industrial operations and specifically designed to treat industrial effluents will be identified by the terms “on-site wastewater systems” and/or “industrial wastewater systems”.

terrestrial or aquatic environments by wet (rain and snow) and dry deposition (Fogg and Duce 1985; Anderson et al. 1994; Kot 2009; Zhao and Liu 2010).

6.1.2 Water and sediment

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 to 63.5 g/L) (see section 3). Boric acid [$B(OH)_3$] is in a pH-dependent equilibrium with borate anions [$B(OH)_4^-$] under environmentally and physiologically relevant concentrations (CCME 2009). At acidic pH, undissociated boric acid is the predominant species, whereas at alkaline pH (that is, above the 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 oxidation-reduction reactions or biotransformation (Kot 2009). In natural waters (pH 6 to 8), polyborates and other minor complexes with transitional metals and fluoride may also exist (Basset 1980 as cited in Kot 2009). Complexation of boric acid with environmentally important cations (that is, Al^{3+}, Fe^{3+}, Ca^{2+}, and 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 as cited in Keren and Communar 2009; Parks and Edwards 2005). It has been hypothesized that adsorption to suspended solids explains the elevated boron concentrations 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 systems (for example, median removal rate of 2.2%) (ECCC 2019). 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 as cited in Kot 2009). However, a low sediment-water (K_{sdw}) partition coefficient value (log K_{sdw} = 0.29) (Gerke 2011a) and a low tendency to form complexes with environmentally common cations suggest that boric acid will generally tend to remain in the water column. Therefore, sediments are not anticipated to be a significant sink for boric acid in freshwater ecosystems. Boric acid in sediments may also reflux back 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 (that is, 1.1 mg B/L) were hypothesized to be caused by the leaching of adsorbed boron on soil minerals (Bonanno 2011).

6.1.3 Soil

Boron exists in soils in 4 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 (for example, tourmaline) is insoluble and non-bioavailable. Adsorbed or organically bound boron is also insoluble but may be released as boric acid via desorption and organic matter degradation (Gupta 1993). 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 extraction from a saturated soil by water (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).

Boric acid is highly mobile in soils, consistent with its low soil-water partitioning coefficient (log K_{sw} = -1.06 to 2.2) (Singh 1971; Elrashidi and O'Connor 1982; Buchter et al. 1989; Sauvé et al. 2000; Janik et al. 2010 as cited in Borax Europe 2012; Majidi et al. 2010; Equilibrium Environmental Inc. 2012) and is expected to follow the water flux (Kot 2009). Boric acid does not undergo oxidation-reduction reactions or volatilization in soils; therefore, its concentration in soil solution is mainly controlled by adsorption reactions (Goldberg 1997). The main factors affecting boric acid adsorption in soils and its bioavailability are soil moisture, soil solution pH, soil texture (coarse vs. fine), soil contents (organic matter, clays, and metal hydroxides), and temperature (Goldberg 1997). The adsorption of boron reaches a maximum at pH 9, coinciding with an increase in the concentration of borate anions, which have more affinity with clays than boric acid does (Keren and Bingham 1985). Adsorption to metal hydroxides (for example, 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 solutions of boric acid amended soil did not decrease by aging over a period of 5 months, indicating that added boric acid is not quickly bound and is highly mobile. Because of its incorporation into silicate structures or biomass, it was determined that boron that is naturally present in soils is much less soluble and therefore much less bioavailable than boric acid added to soil (Mertens et al. 2011).

6.2 Environmental persistence

A metalloid ion like boric acid is considered infinitely persistent because it cannot degrade any further, although 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 in the form of boric acid or the borate anion. Biodegradation and photodegradation are not applicable to boric acid or other inorganic boron-containing substances.

6.3 Potential for bioaccumulation

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

6.3.1 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 to 766 L/kg dw (dry weight) (geometric mean of 75 L/kg dw) have been measured in filamentous algae from the lower San Joaquin River and some of its tributaries (Saiki et al. 1993). In studying the remediation of boron-polluted waters using duckweed (*Lemna gibba*), Del-Campo Marin and Oron (2007) also reported moderately high BCF values of 1,100 to 2,400 L/kg dw at boron concentrations of 0.3 to 1 mg/L in water. Lower BCF values of 500 L/kg dw and less than 300 L/kg dw were observed in duckweed exposed to higher boron concentrations (for example, 1.0 to 2.5 mg/L and greater than 5 mg/L) (Del-Campo Marin 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*) or 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 7 to 60 L/kg dw in chironomids, 8 to 60 L/kg dw in amphipods, and 6 to 38 L/kg dw in crayfish. Little to 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 to 16.7 mg/L in water and from 1.98 to 2.84 mg/kg in invertebrates, leading to BAF values of 0.085 to 0.15 L/kg dw (Arslan 2013). Low BAF values ranging from 0.176 to 8.7 L/kg dw 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 to 3.45 mg B/L) and sediment (15.7 to 32.3 mg B/kg) (Emiroglu et al. 2010). Boric acid does not bioaccumulate in fish, as indicated by BAF values of less than 0.1 L/kg dw in Chinook salmon (*Oncorhynchus tshawytscha*) (Hamilton and Wiedmeyer 1990) and BCF values of 0.3 L/kg dw 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 L/kg dw), northern pike (*Esox lucius*) (63 L/kg dw), lake cisco (*Coregonus artedi*) (64 L/kg dw), lake trout (*Salvelinus namaycush*) (75 L/kg dw), and white sucker (*Catostomus commersonii*) (198 L/kg dw) (Tsui and McCart 1981). BAFs calculated for fish from streams where boron concentrations ranged from 8.6 to 16.7 mg/L varied from 0.57 to 0.92 L/kg dw 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 for European chub (*Leuciscus cephalus*), which was calculated using concentrations measured in the muscle, liver, gills, and head, ranging from 0.78 to 41 L/kg dw. In addition, low BAF values were reported for mosquitofish (BAF of 4 L/kg dw), bluegill (*Lepomis macrochirus*) (BAF of 2 L/kg dw), and largemouth bass (*Micropterus salmoides*) (BAF of 0.7 L/kg dw) (Saiki et al. 1993).

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

6.3.2 Soil

In general, less than 5% of the total boron background concentration in soils is bioavailable (hot water-soluble) to plants (Gupta 1993). Bioavailable boron is absorbed by roots as undissociated boric acid (Mengel and Kirkby 1982; Marschner 1995; Hu and Brown 1997). Dicotyledon plants (for example, legumes) in general require 4 to 7 times more boron (20 to 70 mg/kg) than monocotyledons (*Graminae*) (5 to 10 mg/kg) (Bergmann 1988 as cited in Marschner 1995; Bergmann et al. 1995; Marschner 1995). According to Kabata-Pendias (2011), the average concentration of boron is 0.7 to 4.3 mg/kg in grains, 5 to 7.4 mg/kg in grasses, and 14 to 40 mg/kg in clover. Shacklette et al. (1978) showed that trees and shrubs (usually containing 50 to 500 mg/kg of boron) generally contain 2 to 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 (*Raphunus sativus*), and amaranth (*Amaranthus crentus*) ranged from 63 to 93 mg/kg, whereas the concentrations of soluble and total boron in soil were 3.8 mg/kg and 6.4 mg/kg, respectively. Therefore, bioaccumulation potential is low for these species. At boron concentrations of 5 mg/L in irrigation water, mean levels of boron in shoots of wheat (*Triticum aestivum*), tomato (*Solanum lycopersicum*), and silver beet (*Beta vulgaris*) were greater, ranging from 701 to 1,110 mg/kg (Ayars et al. 1990 as cited in Nable et al. 1997; Ayars et al. 1993). Therefore, for some plants, boric acid bioaccumulation can be high, which is consistent with the fact that boron is an essential nutrient for plants (see section 7.1).

7. Potential to cause ecological harm

7.1 Essentiality

The essentiality of boron has been demonstrated in most plants and some animals (ATSDR 2010; US EPA 2015a). Boron, primarily absorbed as boric acid, is an essential micronutrient for plant growth, development, and seed quality (Pilbeam and Kirkby 1983; Marschner 1995; Hu and Brown 1997; Brown et al. 1999; Dordas et al. 2007). There are indications that boron is involved in cell wall structure (Hu and Brown 1994;

Brown et al. 2002), cell membrane integrity (Schon and Blevins 1990; Marschner 1995), sugar metabolism (Marschner 1995), biological membrane bindings, conversion of glucose-L-phosphate sugars to starch, and metabolism of nucleic acids (Cakmak and Römheld 1997). Boron also 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 (Goldbach 1985; Marschner 1995), and plasma-membrane-bound H^+-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 with frogs given a diet supplemented with boric acid (Fort et al. 1998, 2002). Tests conducted using water with low concentrations of boron and water supplemented with boric acid showed that boron is essential for the development of zebrafish (*Danio rerio*) embryos 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 0.002 mg B/L, respectively (Rowe et al. 1998).

7.2 Ecological effects assessment

Boric acid is generally measured as boron (B) content in laboratory or media matrices. Therefore, endpoints of ecotoxicity testing for boric acid in this ecological assessment are reported as boron equivalent concentration: mg B/L or mg B/kg.

7.2.1 Effects on aquatic organisms

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 (Environment Canada 2014a). Chronic toxicity data are of greater relevance and weighted more heavily as a line of evidence than acute data in this ecological assessment because they are a more sensitive indicator of potential harm to aquatic organisms from long-term exposures. Given the persistence of boric acid, long-term exposures are particularly pertinent.

Acute toxicity studies were identified for 35 species: 2 algae species, 1 aquatic plant species, 15 invertebrate species, 15 fish species, and 2 amphibian species (Environment Canada 2014a). Acute toxicity endpoints ranged from a 3-day no-observed-effect concentration (NOEC) (teratogenesis at hatching) of 0.109 mg B/L for largemouth bass (*Micropterus salmoides*) embryos to a 96-hour lethal concentration (LC_{50}) of 979 mg B/L for mosquitofish (*Gambusia affinis*) and a 48-hour LC_{50} of 1,376 mg B/L for midges (*Chironomus decorus*) (Birge and Black 1977; Maier and

Knight 1991; Black et al. 1993). Data from these studies are not included or discussed further in this ecological assessment because they are not used to derive a PNEC.

Chronic toxicity studies were identified for 40 species, including 5 algae species, 8 plant species, 8 invertebrate species, 7 fish species, 7 amphibian species, 2 species of zooplankton, 1 species of cyanobacteria, 1 species of protozoan, and 1 species of bacteria (Environment Canada 2014a). 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 (*Oncorhynchus mykiss*) at embryo-larval stages in lab-reconstituted water to a 32-day LC_{50} of 138 mg B/L for rainbow trout (*Oncorhynchus mykiss*) (Birge and Black 1977; Black et al. 1993). A lower chronic 28-day NOEC (survival and teratogenesis) of 0.001 mg B/L for embryo-larval stages of rainbow trout (*Oncorhynchus mykiss*) is generally considered unreliable (EURAR 2007). This endpoint is several orders of magnitude lower than other toxicity values, and the effects observed on rainbow trout (*Oncorhynchus mykiss*) may have resulted from boron deficiency (that is, 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 for the aquatic toxicity of boric acid is not well understood; however, it is believed to be generally less significant than for other metalloids or metals (for example, copper) (Black et al. 1993; Dethloff et al. 2009). Toxicity tests on rainbow trout (*Oncorhynchus mykiss*) performed with natural waters showed higher toxicity threshold concentrations (up to 180 times greater) than those observed with reconstituted water (Black et al. 1993), indicating that the composition of natural waters may reduce the toxicity of boron to fish and possibly other aquatic organisms. In general, the toxicity of boron to aquatic organisms in laboratory settings (added as boric acid) is not significantly modified by water hardness (Birge and Black 1977; Hamilton and Buhl 1990; Maier and Knight 1991; Dethloff et al. 2009; Soucek et al. 2011). However, a protective effect of very hard waters (greater than 500 mg/L as calcium carbonate [$CaCO_3$]) has been observed in certain acute toxicity tests conducted with invertebrates such as *Daphnia magna* and *Hyalella azteca* (MELP 1996 as cited in Moss and Nagpal 2003) or *Ceriodaphnia dubia* (Dethloff et al. 2009). Increasing sodium, chloride, or sulfate concentrations also do not significantly affect the toxicity of boron to aquatic organisms (added as boric acid) (Maier and Knight 1991; Dethloff et al. 2009), although protective effects of chloride have been observed with *Hyalella azteca* (Soucek et al. 2011). Complexation of boric acid and borates with organic compounds (for example, *α*-hydroxy carboxylic acids) and adsorption to PM have been hypothesized to be potential modifying factors for boron toxicity to aquatic organisms (Black et al. 1993). Dissolved organic carbon (DOC) exceeding 2 mg/L has been shown to reduce the acute toxicity of boron to *Ceriodaphnia dubia* (Dethloff et al. 2009).

In 2009, the Canadian Council of Ministers of the Environment (CCME) published short- and long-term Canadian Water Quality Guidelines (CWQGs) for boron for the protection of aquatic life (CCME 2009) following the CCME protocol (CCME 2007). The long-term CWQG was developed using a species sensitivity distribution (SSD) approach (Figure

7-1). A total of 28 data points for fish, invertebrates, plants and algae, and amphibians, generated using boric acid or boric acid-equivalent compounds, were used to derive the long-term CWQG (CCME 2009). The long-term CWQG of 1.5 mg/L for boron (that is, a hazardous concentration for 5% of species [HC_5], corresponding to the 5th percentile of the SSD) for the protection of freshwater organisms was selected as the freshwater predicted no-effect concentration (PNEC) in this ecological assessment. This PNEC value is comparable to or more protective than recent HC_5 values of 1.7 mg B/L and 3.8 mg B/L, which were calculated with an SSD approach using chronic aquatic toxicity data (EURAR 2007; Borax Europe 2012). Assessment factors (AFs) were applied to these latter values in the PNEC derivation process (EURAR 2007; Borax Europe 2012).

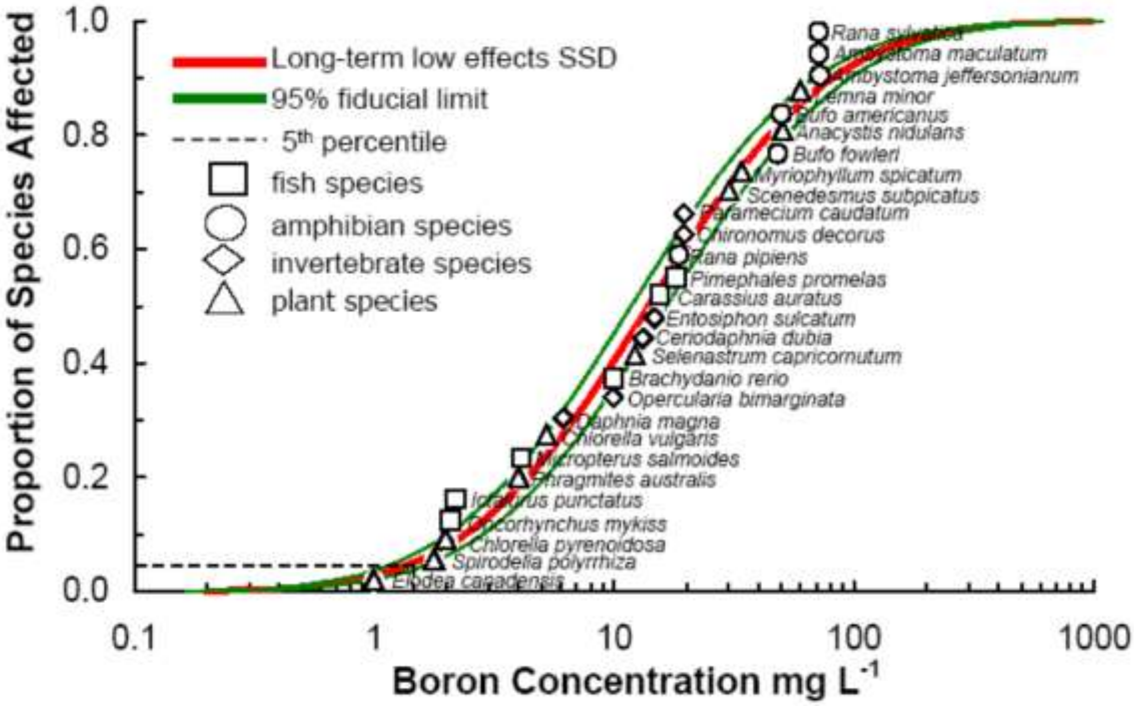

Figure 7-1. Species sensitivity distribution (SSD) for boron based on chronic toxicity data for freshwater organisms (CCME 2009). The log-normal model fit to data is shown on the graph along with the 95% confidence intervals.

[Figure 7-1 illustrates the species sensitivity distribution (SSD) based on acceptable long-term no- and low-effect endpoints for 28 aquatic species (6 fish, 6 invertebrates, 10 plants and algae, and 6 amphibians). The chronic SSD is used to derive the boron long-term predicted no-effect concentration (PNEC) for freshwater organisms. The log-normal model fit to data is shown on the graph, along with the 95% confidence intervals. The 5th percentile of the distribution (HC5) was calculated at 1.5 mg B/L and selected as the long-term PNEC for boron in fresh water. This figure shows that the sensitivity of the freshwater organisms to boron follows an S-shaped curve.]

Recent aquatic toxicity studies, or studies that were unavailable for the 2009 CWQG derivation, were systematically reviewed to confirm the protective nature of the PNEC.

Additional chronic toxicity values for one amphibian, 3 invertebrates, one fish and 3 plant or algal species were all above the PNEC value of 1.5 mg B/L (ranging from 6.6 to 34.6 mg B/L) (Hansveit et al. 2001; US EPA 2010; Fort 2011; Soucek et al. 2011; Hall et al. 2014; Gur et al. 2016), confirming that the PNEC is adequately protective of a wide variety of freshwater organisms.

7.2.2 Effects on sediment-dwelling organisms

Sediment toxicity data are limited for boric acid. Data for benthic organisms were identified for freshwater midges (*Chironomus riparius*), blackworm (*Lumbriculus variegatus*), and fatmucket mussel (*Lampsilis siliquoidea*) (Hooftman et al. 2000; Gerke et al. 2011a, 2011b; Hall et al. 2014). Toxicity values derived on the basis of 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_{25} of 363.1 mg B/kg for the fatmucket mussel (Gerke et al. 2011a; Hall et al. 2014). Toxicity values derived on the basis of porewater concentrations ranged from a 21-day NOEC (growth) of 10 mg B/L for the fatmucket mussel to a 28-day LOEC (emergence) of 59 mg B/L for the freshwater midge (Hooftman et al. 2000; Hall et al. 2014) (see Appendix B-1).

Owing to its high water solubility, boric acid is rapidly depleted from spiked sediments (Gerke et al. 2011a; Borax Europe 2012; Hall et al. 2014). In the study conducted by Gerke et al (2011a), the test chambers were prepared 2 days prior to study initiation, whereupon midges were added for a total duration of 30 days. The boron load in overlying water increased from 31% of the total load on day 2 to 75% on day 30, with a concentration of 20.9 mg B/L in overlying water. 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 is comparable to a 28-day NOEC of 32 mg B/L measured by Hooftman et al. (2000) for the same species. Therefore, the chronic toxicity observed for the freshwater midge may mostly be attributed to boron in the water column (Borax Europe 2012) and not 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 done by Hall et al. (2014) for the aquatic worm (*Lumbriculus variegatus*). The worm growth endpoint showed high variability (possibly owing 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 and not the solid phase (Hall et al. 2014).

Owing to the low partitioning of aqueous boric acid to sediment (see section 6.1.2) and the limited sediment toxicity studies available for boric acid, exposure via this compartment was given low weight as a line of evidence. Therefore, a PNEC value was not calculated for benthic organisms.

7.2.3 Effects on soil-dwelling organisms

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 9 different families; 26 plant species, including monocotyledons, dicotyledons, and herbaceous plants and trees; and soil micro-organisms addressing 2 key soil biochemical processes (carbon transformation and nitrification). No studies aiming to establish the efficacy of boric acid as a pest control product (for example, to control ants or termites) were included in this data set (Environment Canada 2014b). Exposure to boric acid in soil is expected to be long term because of its persistence. Therefore, chronic data are of greater relevance than acute data in this ecological assessment because they are a more sensitive indicator of potential harm to soil-dwelling organisms from long-term exposures. All concentrations reported in soil toxicity studies and reports were converted into concentrations of boron equivalence to simplify comparison with the exposure concentrations used to characterize risk. The data were then used to derive a PNEC for boron in soils. Robust Study Summaries were completed for all studies from which toxicity data were taken and used to derive the PNEC.

Reliable chronic data were identified for 25 species, including 13 invertebrate species and 12 plant species. These species were exposed to varying concentrations of boric acid in different types of North American, European, and artificial soils (Environment Canada 2014b). Chronic toxicity values for invertebrates (4- to 63-day NOEC/NOAEC [NOAEC = no-observed-adverse-effect concentration], LOEC/LOAEC [LOAEC = lowest-observed-adverse-effect concentration], and EC/IC$_{10\text{-}50}$ [IC = inhibitory concentration]) ranged from 1.43 to 630 mg B/kg (Becker-Van Slooten et al. 2003; ESG International Inc. and Aquaterra Environmental Consulting Ltd. 2003; Princz and Scroggins 2003; Stantec Consulting Ltd. and Aquaterra Environmental Consulting 2004; Moser and Becker 2009a, 2009b, 2009c, 2009d, 2009e; Moser and Scheffczyk 2009; Princz et al. 2010; Becker et al. 2011; Owojori et al. 2011; Amorim et al. 2012; Smit et al. 2012; Huguier et al. 2013; Environment Canada 2014c). Chronic toxicity values for plants (14- to 90-day NOEC, LOEC, and EC/IC$_{10\text{-}50}$) ranged from 1.75 to 242 mg B/kg (Gestring and Soltanpour 1987; Bagheri et al. 1994; Anaka et al. 2008; Hosseini et al. 2007; Förster and Becker 2009; Becker et al. 2011; Miller 2013; Environment Canada 2014c). Symptoms of toxicity in plants include yellowing, spotting, or drying of leaf tissues (Gupta et al. 1985).

The toxicity of boric acid to soil-dwelling 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 6.1.3) are dependent on soil moisture, pH, soil texture, and soil content. Differences in soil toxicity values of a factor of approximately 2 for *Enchytraeus albidus* and *Folsomia candida* in Landwirtschaftliche Untersuchungs- und Forschungs-Anstalt (Agricultural Research Institute, 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 levels of organic matter and clay content than LUFA soil (Amorim et al. 2012). However, minimal impacts of soil aging (up to 5 months) and sorption on the bioavailability of boric acid to plants in boric acid-amended soil indicate 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 to occur; consequently, they are not considered further in this ecological assessment for the characterization of effects. Additionally, because the fraction of bioavailable boron in ambient background concentrations is low (see section 6.1.3), the potential contribution of ambient background concentrations to the toxic effects of boric acid on soil-dwelling organisms is considered negligible compared with boric acid concentrations added to soil as a result of anthropogenic activities, which are much more bioavailable. On the basis of these considerations, the added risk approach, which assumes that only the fraction of anthropogenic added boron (as boric acid) in soil may contribute to risk, was used to characterize the effects of boric acid on soil-dwelling organisms (ICMM 2016a). Therefore, the PNEC derived for soil organisms focuses on the added fraction of boric acid in soil only and is referred to as a $PNEC_{added}$.

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 2016b), allowing the derivation of a PNEC using an SSD approach. 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 for use in the SSD were chosen following the CCME protocol for the derivation of CWQGs (CCME 2007) and include, in decreasing order of preference, EC_{10}, EC/IC_{20}, IC_{25}, 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 (for example, biomass, growth) within one study, the lowest endpoint toxicity value for a given species was selected.

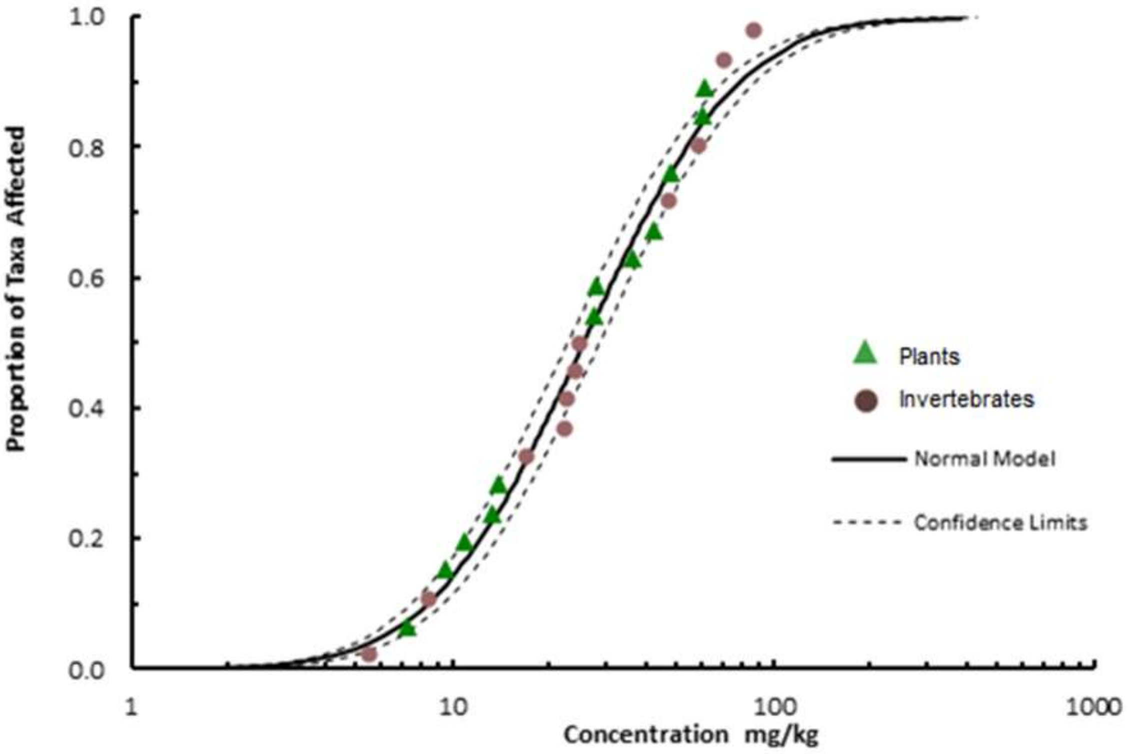

Figure 7-2. Species sensitivity distribution (SSD) for boron based on chronic toxicity data for soil-dwelling organisms. The Normal Model fit to data is shown on the graph along with the 95% confidence intervals.

[Figure 7-2 illustrates the species sensitivity distribution (SSD) based on acceptable no- and low-effect endpoints for 23 species. The chronic SSD is used to derive a boron long-term predicted no-effect concentration (PNEC) for soil-dwelling organisms. The Normal Model fit to data is shown on the graph, along with the 95% confidence intervals. The 5th percentile of the distribution (HC5) was calculated at 6.08 mg B/kg and selected as the long-term PNEC for boron in soils. This figure shows that the sensitivity of the soil-dwelling organisms to boron follows an S-shaped curve.]

The software SSD Master v3.0 (SSD Master 2010) was used to plot the SSD (Figure 7-2). Several cumulative distribution functions (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 on the basis 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* less than 0.05) compared to a (A^2) = 0.259 (*p* less than 0.05) for the Normal Model. However, the confidence interval spread of the Extreme Value was greater (that is, 2.78 to 5.06 mg B/kg), 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 mg B/kg and 6.82 mg B/kg, respectively.

The HC_5 of 6.08 mg B/kg calculated from the SSD is selected as the PNEC for soil-dwelling organisms. This value is derived from a chronic toxicity data set that covers multiple species and taxa; therefore, no AF is used to derive the added PNEC. Hence, the $PNEC_{added}$ for soil-dwelling organisms is 6.08 mg B/kg.

7.3 Ecological exposure assessment

Boric acid is generally measured as boron (B) content in the environmental media matrix. Therefore, environmental concentrations of boric acid are reported as concentrations of boron in this ecological assessment.

7.3.1 Background concentrations

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).

Concentrations, where available, of recent total and dissolved boron measured in water bodies across Canada (Table 7-1) indicate that while some of the higher concentrations may be related to contributions from point-source anthropogenic releases, concentrations up to the 50th percentile should be representative of the regional biogeochemical background concentration (ICMM 2016c). These data were collected between 2005 and 2015 as part of Environment Canada’s Monitoring and Surveillance Program under the CMP (ECCC [modified 2019]).

Table 7-1. Ambient concentrations of boron in surface waters across Canada (2005 to 2015)

Location	Concentration range (µg B/L)	Median (µg B/L)	Reference
Pacific and Yukon Region[a]	0.025 to 510 (dissolved = 0.25 to 81.5)	3.4 (dissolved = 4.5)	ECCC [modified 2019]
Prairie and Northern Region[b]	0.05 to 56.7(dissolved = 0.05 to 56.8)	7.7 (dissolved = 7.3)	ECCC [modified 2019]
Ontario Region (Hudson's Bay)[c]	1.2 to 806 (dissolved = 1.2 to 729)	30.86 (dissolved = 29.48)	ECCC [modified 2019]
Ontario Region (Erie-Superior-Ontario)[d]	0.1 to 65.7	8.70	ECCC [modified 2019]
Québec Region[e]	0.9 to 160	12	ECCC [modified 2019]
Atlantic Region[f]	0.1 to 58.3	5.3	ECCC [modified 2019]

[a] Sample size: total concentration (n=10,850) and dissolved (n=1,770)
[b] Sample size: total concentration (n=1,127) and dissolved (n=1,006)
[c] Sample size: total concentration (n=808) and dissolved (n=786)
[d] Sample size: total concentration (n=108)
[e] Sample size: dissolved concentration (n=996)
[f] Sample size: total concentration (n=1,328)

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). Compared with sandy soil, higher concentrations of boron may be found in clay, loam, or soils rich in organic matter (Gupta 1967 as cited in Parks and Edwards 2005). 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 6.1.3). Less than 5% of the total boron in soils is bioavailable to plants (Gupta 1993).

The US Geological Survey (USGS 1984) reported an average boron concentration of 33 mg/kg (concentrations ranged from less than 20 to 300 mg/kg) in surface soils from the conterminous United States, with concentrations slightly higher in the eastern United States. Boron concentrations in soil are also high in California. In Canada, there are less data available on the concentration of total boron in soil, but median total boron concentrations reported for 20 sites sampled throughout Canada between 1962 and 1973 ranged from 10.7 to 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 ranged from 1 to 90 mg/kg, with median concentrations ranging from 1 to 26 mg/kg; concentrations are high in the Peace River area but are considered deficient in the rest of British Columbia (BC MOE 2017). In New Brunswick, the baseline boron concentration in soil, characterized as 97th percentile boron soil concentration, is reported as 8 mg/kg (Government of New Brunswick 2005). In Alberta, hot water-extractable boron measured in soil from 42 benchmark sites across the province ranged from 0.29 to 2.32 mg/kg with a mean of 0.92 mg/kg (Penney 2004). In the Flin Flon soil study, hot water-extractable boron ranged from 0.1 to 19 mg/kg from residential surface soils around east and west Flin Flon and Channing, Manitoba, and Creighton, Saskatchewan (Jacques Whitford AXYS Ltd. 2008).

7.3.2 Approach for exposure characterization

Exposure scenarios were developed for various activities that represent significant sources of release of boric acid, its salts and its precursors to the environment (see section 4.2). These scenarios are presented in this section by sectors of activity or uses: 1) coal-fired power generation stations, 2) metal ore mining, 3) base metals and precious metals smelting and refining, 4) coal mining, 5) oil sands extraction and processing, 6) oil and gas extraction, 7) agriculture, 8) pulp and paper manufacturing, 9) wastewater systems and waste management, 10) rubber manufacturing, 11) surface finishing, 12) fibreglass insulation and manufacturing, and 13) generic activities. Activities or uses related to consumer products (Tables 4-4 and 4-5) were evaluated in several exposure scenarios: wastewater systems and waste management (section 7.3.2.9) takes into account boron-containing products available to consumers, including soaps and detergents, cosmetics, eye and self-care, water treatment chemicals, and veterinary products (see section 4.2.3) that are subject to down-the-drain releases after use; products available to consumers that end up in landfills at the end of their life cycle were also taken into account. Generic scenarios (section 7.3.2.13) take into account products available to consumers and industrial dischargers, including construction products (for example, cellulose/fibreglass insulation, gypsum and wood products), fertilizers and pesticides manufacturing, arts and crafts materials and toys, DIY products (including adhesives and sealants, automotive maintenance, home maintenance, paints and coatings), electrical equipment, and more. (see section 4.2.3).

For each scenario, predicted environmental concentrations (PECs) were calculated for the aquatic and/or soil environment using measured boron concentrations in surface water and soil, when applicable. Both dissolved and total boron concentrations were considered where available, with a preference given to dissolved boron concentrations. PECs were not developed for air because boric acid released to this compartment is expected to be removed by wet and dry depositions 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 owing to its high water solubility.

When measured effluent concentrations of boron were available, PECs were also calculated using effluent and background concentrations according to the equation below:

$$PEC\ (\mu g/L) = C_b\ (\mu g/L) + \left(\frac{C_{eff}\ (\mu g/L) - C_b\ (\mu g/L)}{R_f\ (L/d)/R_{eff}\ (L/d)}\right)$$

[Alt-text for equation: PEC (µg/L) = C_b (µg/L) + ((C_{eff} (µg/L) – C_b (µg/L)) / (R_f (L/d) / R_{eff} (L/d)))
]

Where C_b is the default background value of 0.031 mg B/L for boron (see section 7.3.1). C_{eff} is the concentration of boron in effluent. The term R_f/R_{eff} represents dilution of the effluent into the receiving water, where R_{eff} is the effluent flow rate and R_f is the 10th percentile of the receiving water flow. For this ecological assessment, the term R_f/R_{eff} was replaced with 10 as the standard maximum effective dilution factor that was used for large lakes.

When measured concentrations of boron in surface waters and effluents were not available, PECs were determined with model predictions using conservative assumptions for the first calculations; to increase the realism of the scenario, these assumptions were then refined where a potential concern was identified. For many industrial sectors, the main compartment 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 systems (indirect discharges). For each of these sectors, estimated aquatic concentrations (EACs) are the environmental concentrations resulting from the releases emitted by these facilities or activities (for example, 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 (50th percentile) background concentration of boron in water to the range of the related EACs (that is, 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 (that is, releases from consumer use; see section 7.3.2.9). As a conservative approach, the highest median background concentration of 0.031 mg B/L (Table 7-1) was used (see section 7.3.1).

For the soil compartment, measured concentrations in the vicinity of a site were compared with concentrations from reference sites representing regional background conditions when data were available (see section 7.3.2.3). When concentrations at reference sites 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 the potential contribution of bioavailable boric acid from ambient soil background concentration is minimal. It is assumed that a default boron bioavailability in soil equal to zero is considered reasonable (Struijs et al. 1997) because the bioavailable fraction of non-anthropogenic boron in soils is known to be low (Gupta 1993). Conservative assumptions were nevertheless used to generate soil PEC_{added} values, including the use of a high soil-water partitioning coefficient value (that is, log K_{sw} = 2.2); it was also assumed that there was no loss via runoff, leaching, or uptake by plants in modelling. PEC_{added} values were generated to estimate the addition, resulting from air emissions (see sections 7.3.2.1, 7.3.2.5, and 7.3.2.12) or the application of biosolids (see section 7.3.2.9), of boric acid in soil expressed as boron. Further details are available in ECCC (2021b, 2021f, 2021h).

7.3.2.1 Coal-fired power generation stations

Boron is naturally present in coal, in concentrations ranging from 16 to 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 for the generation of 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 through discharges from power plant wastewater effluents, fly ash and bottom ash containment areas (that is, ash lagoons), coal piles, or groundwater seepage from containment areas. Additional information on boron releases associated with this sector can be found in ECCC (2021b).

An exposure scenario was developed for the Wabamun Lake area located within the North Saskatchewan River watershed on the basis of boron concentrations measured in various environmental media. This area is used as a realistic worst-case scenario to assess releases from coal-fired power stations in Canada. Between 2002 and 2005, a number of water quality surveys were conducted by the Alberta Ministry of the Environment at Wabamun Lake (Alberta Environment 2002, 2003a, 2003b, 2006), which revealed relatively high measured concentrations of boron (Table 7-2). Several coal mines are located in the Wabamun Lake area, which is in the vicinity of the power stations. Measured concentrations in the lake water may therefore include contributions from both coal-fired power generation and coal mining industrial activities. Soil samples were also 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 2002); no 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 4 years), as well as 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, 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 2014d). Added boron concentrations in soil resulting from air emissions over a period of 50 years were estimated to be relatively low (Table 7-2).

Table 7-2. Summary of boron PECs in the Wabamun Lake area, Alberta

Medium	PEC range (mg B/L or mg B/kg)	PEC median (mg B/L or mg B/kg)	Sample size (n=)	Sampling period	Reference
Water	0.786 to 1.0	0.884	116	1996 to 2005	Alberta Environment 2002, 2003a, 2003b, 2006
Soil	NA	0.322[a]	NA	2002	GSC 2002; Environment Canada 2014d

Abbreviations: PEC, predicted environmental concentration; NA, not available

[a] The estimated concentration of boron added to soil (that is, PEC_{added}) was obtained using the boron deposition rate calculated by the GSC (2002).

7.3.2.2 Metal ore mining

The term “mining” is used in a broad sense to include ore extraction, quarrying, and beneficiating (for example, crushing, screening, washing, sizing, concentrating, and flotation), which are customarily done at the mine site (Statistics Canada [modified 2018]). Mining activities can therefore 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 that occur in close association with much larger amounts of waste minerals that have no economic value (gangue). These valuable ore minerals are separated (liberated) from the gangue in milling operations to obtain a higher quality metal. Major steps in ore processing at milling facilities include grinding and crushing, chemical or 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 2024c), where they serve as fluxes during the fire assaying of ore or the 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 (US EPA 1994; Paliewicz et al. 2015). For the year 2012, less than 4 companies indicated purchasing between 10 and 100 tonnes of a boric acid precursor, and less than 4 companies indicated purchasing between 1 and 10 tonnes of the same precursor as a result of voluntary stakeholder engagement activities (Environment Canada 2013c). Because borates may be a major ingredient of fluxes in precious metal recovery (up to 60 wt %) (Borax 2024c), high concentrations of boron may be found in the slags generated by this activity (Paliewicz et al. 2015). Laboratory leachability tests conducted on pulverized slag samples from 3 Canadian mining operations showed that a significant amount of boron (3 to 12 wt % of the initial mass of solid slag) may be released within 24 hours (Paliewicz et al. 2015). Therefore, it is possible that boric acid is released into the environment as a result of the mining and production of metal concentrates.

Samples were collected from a tailings area receiving wastes from a former milling facility that had processed an estimated 60 000 tonnes of boron-containing slag and refinery bricks (75% slag; 25% brick) (Paliewicz et al. 2015). Boron concentrations were as high as 242 mg B/L in local groundwater and as high as 9.1 mg B/L in locally discharged surface water (Paliewicz et al. 2015). As described in Paliewicz et al. (2015), the study did not examine boron concentrations in the river adjacent to the tailings area, but it determined from the drainage pattern of the tailings area that the river flowing in the vicinity of the milling site was likely receiving discharges from the tailings area as surface run-off, groundwater seepage, or decanted dam water.

Canadian metal mines subject to the *Metal and Diamond Mining Effluent Regulations* (MDMER) under the *Fisheries Act* (Canada 2019) must conduct effluent and water quality monitoring as part of environmental effects monitoring (EEM). Reports from 154 metal ore mining and milling sites between 2004 and 2020 were reviewed (EEM 2021). Measurements of boron concentrations in effluent or in the receiving environment where effluent is discharged were available for 115 sites (approximately 74% of all sites) from 2003 to 2020, including 14 sites in the Quebec region, 17 sites in the Atlantic region, 17 sites in the Pacific-Yukon region, 30 sites in the Northern-Prairie region, and 37 sites in the Ontario region. Boron concentrations were less than or equal to 0.2 mg B/L for 101 sites; with respect to the exposure areas, 7 sites had boron concentrations of between 0.2 mg B/L and 0.5 mg B/L, 6 sites had boron concentrations of between 0.5 mg B/L and 1.4 mg B/L, and 1 site (Site 6) had very high concentrations of 2.8 to 20 mg B/L (Table 7-3) (EEM 2021). Boron concentrations reported in the effluent at one site (less than 0.7 mg B/L) could not be interpreted owing to a high detection limit; however, concentrations in the receiving water of the site are expected to be low when dilution is considered.

Of the sites showing boron concentrations equal to or above 0.5 mg B/L in the exposure areas, 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, Site 6 is a mill that processes a range of ores and feeds, and Site 7 is a gold mine that ceased operation in 2004, although its effluents continued to discharge seasonally. Further details are available in ECCC (2021c).

Table 7-3. Summary of PECs calculated from measured boron concentrations in surface water near metal mines and mills (EEM 2021)

Site and type of facility	Reference or exposure area	PEC range (mg B/L)	Sample size (n=)	Sampling period
108 mining sites	Exposure	Negligible to ≤0.5	NA	2004 to 2020
Site 1 – mine and smelter	Exposure	0.82[a] to 1.2[a]	10	2011 to 2015
Site 1 – mine and smelter	Reference	<0.01[a,b] to 0.044[a]	10	2011 to 2015

Site 2 – mine	Exposure	0.29 to 0.56	2	2004
Site 2 – mine	Reference	0.003[b] to 0.023	3	2004
Site 3 – mill	Exposure	0.01[b] to 1.3	12	2011 to 2014
Site 3 – mill	Reference	<0.01[b] to 0.01	10	2011 to 2014
Site 4 – multiple mines	Exposure	0.17 to 0.91	54	2003 to 2016
Site 4 – multiple mines	Reference	0.006 to 0.32	73	2003 to 2016
Site 5 – mill	Exposure	0.047 to 0.69	6	2004 to 2007
Site 5 – mill	Reference	0.013 to 0.016	2	2004 to 2007
Site 6 – mill	Exposure	2.8 to 20	22	2010 to 2019
Site 6 – mill	Reference	<0.01[b] to 0.016	22	2010 to 2016
Site 7 – mine	Exposure	0.02[a] to 1.4[a]	50	2015 to 2018
Site 7 – mine	Reference	0.013[a] to 0.017[a]	8	2015 to 2018

Abbreviations: NA, not applicable; PEC, predicted environmental concentration

[a] Dissolved boron concentrations

[b] Method detection limit

Concentrations of boron at all 7 sites were higher in the exposure areas than in the respective reference areas (Table 7-3), indicating the potential anthropogenic addition of boron to the receiving environment at these sites. Site 6 showed significantly elevated concentrations of boron in the receiving environment (that is, 2.8 to 20 mg B/L), with median boron concentrations in the receiving surface water of 19.0 mg B/L and 15.4 mg B/L in 2010 and 2013, respectively (EEM 2021). Since 2013, the facility has taken measures (for example, they stopped processing feeds with high boron concentrations in 2013 and covered an inactive portion of the pre-2013 tailing area with clay in 2015) to reduce boron releases to the environment by adopting a Boron Reduction Strategy under provincial certificates of approvals (Study submission 2016). Accordingly, median concentrations in the receiving water were between 9.3 and 11.5 mg B/L from 2016 to 2019 (EEM 2021), dropping to nearly half of 2010 levels. Information from the facility (Study submission 2016) suggested that the runoff from the tailings had a significant effect on boron loading and the high concentrations subsequently measured in the receiving water.

7.3.2.3 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 4 companies whose primary sector of activity is base metal smelting reported importing between 50 and 100 tonnes of a boric acid precursor in 2008 (Environment Canada 2009a). For the year 2012, less than 4 companies indicated purchasing between 100 and 1,000 tonnes of a boric acid precursor, and less than 4 companies indicated purchasing between 1 and 10 tonnes of another boric acid precursor as a result of voluntary stakeholder engagement activities (Environment Canada 2013c). In base metal smelting and gold metallurgy, borates are used as flux, dissolving metallic oxide impurities that may be subsequently removed with slags; it is also used as a cover flux to protect metals against oxidation (Cole and Ferron 2002; Borax 2024c). 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). Paliewicz et al. (2015) 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 concentrates being processed. Releases of boron to the environment from base and precious metals smelting and refining facilities may also occur via air emissions (Environment Canada 2013b) or effluent releases to the aquatic environment as a result of processing activities.

Results from studies conducted near a smelter in British Columbia and near 2 smelters in Manitoba indicate that air emissions may not contribute significantly to boron levels in soils or in water bodies located near smelters (exposure areas) given that these levels are generally comparable to levels from reference areas (CEI 2003; Jones and Phillips 2003; Jones and Henderson 2006; Jacques Whitford AXYS Ltd. 2008; Stantec 2009; Intrinsik Environmental Sciences Inc. et al. 2011). Further details are available in ECCC (2021d).

Elevated boron concentrations are reported in the effluent of a number of smelters, including 3 combined mining and smelting sites that conduct EEM (Ouellet et al. 2013; EEM 2021). Boron concentrations in receiving surface waters in areas downstream of smelter effluent discharges are generally comparable to boron concentrations measured at reference sites (Table 7-4). Elevated boron concentrations were observed at Site 1 (also discussed in the metal ore mining sector exposure characterization in section 7.3.2.2) in surface waters downstream from the effluent discharge of the facility, which is known to use boron compounds in its smelting process (Environment Canada 2013b; EEM 2021). Dissolved boron concentrations ranged from 0.82 to 1.17 mg B/L (total: 1.2 to 1.3 mg B/L) compared to reference site values that ranged from below detection limit (that is, less than 0.01 mg B/L) to 0.046 mg B/L (EEM 2021). Further details are available in ECCC (2021d).

Table 7-4. Boron PECs calculated from measured concentrations in surface waters in the vicinity of base metals smelters and refining facilities

Site	Type of area	PEC range (mg B/L)	Sample size (n=)	Sampling period	Reference
Site 1	Exposure[a]	0.82[b] to 1.17[b]	10	2011, 2015	EEM 2021
Site 1	Reference[a]	<0.01[b,c] to 0.046[b]	10	2011, 2015	EEM 2021
Site 2	Exposure[a]	0.03 to 0.07	8	2010, 2019	EEM 2021
Site 2	Reference[a]	0.002 to 0.006	11	2010, 2019	EEM 2021
Site 3	Exposure[a]	0.016[b] to 0.054[b]	19	2011, 2014	EEM 2021
Site 3	Reference[a]	0.032[b] to 0.044[b]	12	2011, 2014	EEM 2021
Site 4	Exposure	<0.0050[b,c] to <0.010[b,c]	29	2015 to 2016	Ecoscape Environmental

					Consultants Ltd. and Larratt Aquatic Consulting Ltd 2019
Site 4	Reference	<0.0050[b,c] to <0.010[b,c]	18	2015 to 2016	Ecoscape Environmental Consultants Ltd. and Larratt Aquatic Consulting Ltd 2019

Abbreviation: PEC, predicted environmental concentration

[a] EEM 2021, confidential unpublished reports prepared for the EEM provisions of the MDMER

[b] Dissolved boron concentrations

[c] Method detection limit

7.3.2.4 Coal mining

The mining of coal reserves may lead to the release of boron naturally present in coal (16 to 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 runoff from disturbed areas, and leaching from exposed coal-bearing materials or waste rock piles (BC MOE 1978; NRC 1981; Seierstad et al. 1983; Craw et al. 2006). Further details are available in ECCC (2021e).

Most coal mines in Canada are located in Alberta (9) and British Columbia (10). 2 areas in these provinces were selected to be used for exposure scenarios on the basis of 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 showed that boron concentrations downstream of mine activities were slightly elevated compared with concentrations in reference areas (Casey 2005; Frenette 2007) (see Table 7-5).

Table 7-5. Summary of PECs calculated from measured boron concentrations in surface waters near coal mines

Type of area	PEC range (mg B/L)	Number of samples (n=)	Sampling period	Reference
Exposure	0.004 to 0.061	92	1998 to 2007	Casey 2005; Frenette 2007
Reference	0 to 0.017	64	1998 to 2007	Casey 2005; Frenette 2007

Abbreviation: PEC, predicted environmental concentration

7.3.2.5 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 or mining of the deposits (Hitchon et al. 1977; Williams et al. 2001; Frank et al. 2014). Elevated boron concentrations (0.128 to 3.7 mg B/L) have been reported in oil sands process waters (OSPW) from surface mining operations, which are stored in tailing ponds (Renault et al. 1998, 2001; van den Heuvel et al. 1999; Redfield et al. 2004; Gupta 2009; Puttaswamy et al. 2010; Holden et al. 2013; Frank et al. 2014; McQueen et al. 2017; Harkness et al. 2018; White and Liber 2018), while higher concentrations have been reported in OSPW from underground (*in situ*) operations (76.6 to 196 mg B/L) (Williams et al. 2001). Bitumen extraction and processing generate large amounts of coke, and elevated boron concentrations have been measured in coke leachate (495 to 749 mg B/L) (Puttaswamy et al. 2010). Releases of boron to the aquatic environment may occur as a result of surface water runoff 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 processes 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 4 bulk samplers over a 3-month period in the winter of 2012 were higher near oil sands extraction and processing sites, with a maximum average daily deposition rate of 3.6 µg/m^2/day within a 20-km radius, compared with deposition rates of 0.4 and 0.3 µg/m^2/day at distant monitoring stations within a 48- and 68-km radius, respectively (Bari et al. 2014). Over a 50-year period, such a deposition rate would result in an added boron concentration in soil of 0.92 mg B/kg (Table 7-6) (Environment Canada 2014d). Further details are available in ECCC (2021f).

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 7-6) (JOSM [modified 2018]; RAMP [modified 2018]). RAMP designates its monitoring stations as either “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 2015). Baseline stations may reasonably be considered to be representative of “unexposed” conditions and test stations to be representative of “exposed” conditions; however, because oil sands development has been occurring for many decades over a large area, it can be difficult to clearly identify reference stations within the Athabasca River watershed. The highest dissolved boron concentration of 1.7 mg B/L was detected in one measurement at a test station (MAR-2A) located on the MacKay River in the winter of 2010 (RAMP [modified 2018]). 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 to 2012) of 0.059 mg B/L (n=16). Although the cause of the elevated boron concentration measured at station MAR-2A is unknown, on the basis of the data set available, this measurement is considered to be transient.

Table 7-6. Summary of PECs calculated from measured boron concentrations in the Athabasca River watershed

Medium (unit)	PEC range (95th percentile)	Number of samples (n=)	Sampling period	Reference
Water (mg B/L), reference station[a]	0.0086 to 0.85 (0.170)	326	2006 to 2015	RAMP [modified 2018]
Water (mg B/L), exposure station[a]	0.0077 to 1.703 (0.167)	690	2006 to 2015	RAMP [modified 2018]
Water (mg B/L)[b]	0.0001 to 0.172	332	2003 to 2011	JOSM [modified 2018]
Water (mg B/L)[b]	0.0007 to 0.691 (0.176)	2320	2011 to 2015	JOSM [modified 2018]
Soil (mg B/kg)[c]	0.92	NA	2012	Bari et al. 2014; Environment Canada 2014d

Abbreviation: PEC, predicted environmental concentration

[a] Dissolved boron concentrations are presented for the “reference” and “exposure” stations of 43 water bodies in total on the basis of their “baseline” and “test” classification in RAMP (2015). Using aggregated data for all samples, 95th percentile concentrations were calculated for each category.

[b] Difficult to determine whether monitoring stations are for exposure or reference areas.

[c] Added boron concentration to background levels in soil as a result of bulk deposition rates over a period of 50 years (Bari et al. 2014).

7.3.2.6 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 from approximately 1,000 to 50,000 tonnes yearly between 2009 and 2012 (CBSA 2013). They generally serve as crosslinkers to maintain fluid viscosity as temperature increases down the well (US EPA 2012a; FracFocus 2020) or as cement set retardants, lubricants, pH control buffers, hydrogen sulfide scavengers, surfactant alkaline flooding agents, and corrosion inhibitors, in addition to being used in pulsed neutron well logging (Schubert 2016). 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 is fluid that consists not only of the chemical additives that were mixed into the fracturing fluid but also the formation water, which may be high in dissolved solids (CCA 2014). Produced water is water trapped in underground formations that is brought to the surface along with oil and gas (Liang et al. 2018). Boron has been measured in flowback fluid and produced water in Canada (0.05 to 30.6 mg B/L), primarily owing to natural sources found in oil and gas formations (Cheung et al. 2009; MDDEP 2010a).

Provinces and territories are the primary regulators of onshore oil and gas exploration and extraction, including chemical use, water use, water storage, and disposal of wastewater (including flowback fluids and produced water) (Al-rameeni et al 2016; Enserva 2025). 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 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 provincial or territorial regulatory requirements. For example, Alberta sets out boron concentration limits in drilling waste (AER 2022), while some provinces (for example, Quebec and Nova Scotia) have proposed measures to restrict oil and gas drilling and to ban hydraulic fracturing (Manning and Tamura-O'Connor 2022).

7.3.2.7 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 (Schubert 2003). Boric acid precursors are used in Canada as boron micronutrients in fertilizers (see section 4). According to CBSA (2013), between 1,000 and 2,400 tonnes of boric acid precursors were imported yearly into Canada between 2009 and 2012 by companies whose primary activity involves agricultural chemicals. All fertilizers and supplements, including boron-containing fertilizers, that are imported into or sold in Canada are regulated under the *Fertilizers Act* (CFIA 2020).

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, in which shallow-lying saline groundwater with elevated boron concentrations is directed away from fields to ensure crop productivity (Klasing and Pilch 1988 as cited in Eisler 1990; Ohlendorf 2002). Monitoring data for boron in surface water near intensive agricultural areas in Canada 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 that boron levels were below the detection limit of 0.05 mg B/L (Davies 2008).

7.3.2.8 Pulp and paper manufacturing

Between 2008 and 2012, multiple companies in the pulp and paper sector reported importing, purchasing, or using boric acid precursors yearly in amounts from less than 0.1 to 1,000 tonnes (Environment Canada 2009a, 2013b; CBSA 2013). The substances are used as reducing agents to bleach wood pulps and recycled fibres (Ni et al. 2001; Wasshausen et al. 2006), as well as in partial borate autocausticizing (Tran et al. 1999; Mao et al. 2006). Boron is an essential nutrient for plants and trees (Reimann and De Caritat 1998) and is found naturally in the raw materials processed in this sector. Therefore, boron may be released to the environment from pulp and paper mills that do not directly use boric acid precursors in their manufacturing processes, although these releases are anticipated to be small. However, because of the low boron removal from wastewater systems, mills that use boron-containing substances are anticipated to release higher amounts of boron through the discharging of final effluent to the environment (Bryant and Pagoria 2004).

Measured boron concentrations in surface waters in the vicinity of 14 pulp and paper mills across Canada (ECCC 2021g; EEM 2021) are relatively low (Table 7-7). PECs were also derived for 46 mills in Canada using available mill effluent data. Average or median boron concentrations in effluent ranged from non-detectable (method detection limit of up to 0.2 mg B/L) to 4.01 mg B/L (UBC 1996; NCASI 2006; Kovacs et al. 2007; Martel et al. 2010; MDDEP 2010b; ECCC 2021g). 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 corrected average effluent concentration over the 3-day monitoring period at the facility was 1.3 mg B/L (personal communication from MDDELCC to Environment Canada, 2014; unreferenced). Further details are available in ECCC (2021g).

Additional data were provided by the National Council for Air Stream Improvement, which designed, coordinated, and managed a sampling campaign (August 2018 to January 2019) of 30 facilities representing 2 mill process categories (mechanical and chemical) and different wood fibre sources, and covering 4 ecozones in Canada (NCASI 2020). Boron concentrations in effluent were available from 30 mills (17 chemical and 13 mechanical). Average total and dissolved boron concentrations in final effluents ranged from below the detection limit of 0.1 mg/L to 0.710 mg/L. Background boron concentrations in ambient fresh waters (that is, raw intake water or upstream water) ranged from below the detection limit of 0.01 mg/L to 0.030 mg/L. Non-detects were replaced with one-half the reported detection limit for the PEC calculation (see section 7.3.2).

Table 7-7. Boron PECs from measured concentrations in surface waters or effluents for the pulp and paper sector

Type of PEC	PEC range (mg B/L)	Number of samples (n=)	Sampling period	Reference
Reference[a]	<0.01 to 0.069	20	2009 to 2019	ECCC 2021g

Exposure[a]	<0.01 to 0.21	256	2009 to 2019	ECCC 2021g
Calculated from effluent concentration[b]	0.031 to 1.6 (median 0.031 to 0.43)	290	1994 to 2019	UBC 1996; NCASI 2006, 2020; Kovacs et al. 2007; Martel et al. 2010; MDDEP 2010b; MDDELCC 2014 (personal communication; unreferenced)

Abbreviation: PEC, predicted environmental concentration

[a] Data for 14 facilities reported to the EEM (ECCC 2021g)

[b] The PEC range is calculated on the basis of measured median and mean effluent concentrations for mills across Canada. 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 or measured background concentration when available.

7.3.2.9 Wastewater systems and waste management

Wastewater systems (WWS)[6] in municipalities represent a common point of entry for substances to surface water through effluent discharges (see section 7.3.2). PECs calculated from WWS effluent monitoring data are assumed to account for down-the-drain releases of boron from products used by consumers or in combination with industrial releases. The land application of wastewater biosolids is also a potential point of entry to soil.

Empirical monitoring data are available for a number of WWS. For example, data were collected under the CMP monitoring program for 21 facilities located across Canada from 2011 to 2018 (ECCC 2019). A total of 126 influent and final effluent samples were analyzed for total boron (Table 7-8). Boron was detected in all samples, with concentrations ranging from 0.035 to 2.1 mg B/L in influents and from 0.045 to 1.9 mg B/L in final effluents. The median influent and effluent concentrations were identical at 0.16 mg B/L, indicating that removal of boron from wastewater is negligible. Assuming a dilution factor of 10, a range of concentrations in receiving water (0.0045 to 0.19 mg B/L) was obtained. A range of PECs from 0.035 to 0.225 mg B/L was obtained when adding the background boron concentration of 0.031 mg B/L (Table 7-8). Additional data for concentrations of boron in treated wastewater effluents identified for other locations throughout Canada between 1978 and 2012 range from less than 0.01 to 0.7 mg B/L (Cain and Swain 1980; Swain et al. 1998; CWWA 2001; MDDEP 2001; Environment Canada 2013c).

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[6] In this assessment, the term “wastewater 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 system makes no distinction of ownership or operator type (municipal, provincial, federal, indigenous, private, partnerships). Systems that are located at industrial operations and specifically designed to treat industrial effluents will be identified by the terms “on-site wastewater systems” and/or “industrial wastewater systems”.

Because not all down-the-drain releases of boron-containing substances are necessarily captured in the available WWS monitoring data, exposure modelling was also conducted for this sector. Several uses of boron-containing substances potentially resulting in down-the-drain releases that contribute to the cumulative aquatic exposure to boron have been identified in Canada (Environment Canada 2009a, 2013c; ToxEcology Environmental Consulting Ltd. 2012, 2014; CBSA 2013; Cheminfo Services Inc. 2013a, 2013b, 2013c; EHS 2013). Categories of products subject to down-the-drain releases include soaps and detergents, cosmetics, eye and self-care, water treatment chemicals (for example, swimming pool care), and veterinary products. On the basis of Canadian import data (that is, total import minus re-export) from between 2009 to 2012, and 2017 to 2020 from companies involved in these categories of products, and US 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 748 tonnes B/year (Ball et al. 2012; CBSA 2013; Statistics Canada [modified 2021]). A calculation combining information on quantities of boron reaching wastewater systems and information on removal efficiency for different wastewater treatment types (that is, primary and secondary) with information on 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 0.202 mg B/L, resulting in PECs that range from 0.032 to 0.233 mg B/L when a background concentration of 0.031 mg B/L is added. The modelled PECs are similar to the PECs derived from concentrations measured in wastewater effluents. Further details are available in ECCC (2021h).

Boron was also detected in most samples (91 of 108) of primary sludge, secondary sludge, and biosolids collected as part of CMP monitoring activities (ECCC 2019). Concentrations in primary sludge, secondary sludge, and biosolids ranged from less than 0.03 to less than 76 mg/kg dw (median of less than 0.05 mg/kg dw), from less than 0.002 to 16.4 mg/kg dw (median of 6.03 mg/kg dw), and from less than 0.03 to 445 mg/kg dw (median of 21.1 mg/kg dw), respectively (ECCC 2019). Biosolids from wastewater 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 the spreading of biosolids containing boron.

PEC_{added} = boron concentration in biosolids × application rate × number of years ÷ mixing depth × soil density

In a conservative scenario, a maximum application rate of 8,300 kg dry weight per hectare (dw/ha) per year (that is, 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 1,200 kg/m^3 were used (Williams 1991), along with the highest concentration of boron measured in biosolids (57.1 mg/kg dw) from wastewater systems in Canada, that are not incinerated. A period of 10 consecutive years was chosen as the length of accumulation (ECHA 2012). The cumulative boron concentration in soil at the end of this period was calculated to be 1.97 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 (for example, 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 to 42.1 mg B/L (median of 3.8 mg B/L; n=109) (Conestoga-Rovers and Associates 2015). Of these 13 landfills, 5 treat their leachate on site before either sending it to a wastewater system or releasing it to the environment. For these landfills, total boron concentrations in leachate after treatment ranged from 3.1 to 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, boron concentrations in leachates were higher after treatment (Conestoga-Rovers and Associates 2015).

For landfills that send their leachate (treated or untreated) to a wastewater system, the dilution of the leachate in the system's influent and the dilution of the system's effluent in the receiving watercourse are expected to result in concentrations of boron that are below the levels of concern (PNEC) for aquatic ecosystems. 3 landfills, however, release their leachates (treated or untreated) to the environment, to wetlands, to a filtering marsh, or directly to a river. Total boron concentrations measured in leachate (post-treatment, if available) from 2008 to 2013 ranged from 0.8 to 5 mg B/L (n=6), 3.1 to 6.1 mg B/L (n=6), and 3.8 to 6.2 mg B/L (n=3). Using a dilution factor of 10 and adding 0.031 mg B/L for the background concentration yielded PECs of 0.11 to 0.65 mg B/L for all 3 sites (Table 7-8).

Table 7-8. Summary of PECs 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)[a]	0.035 to 0.225	NA	1978 to 2018	ECCC 2019
Water, modelled for down-the-drain releases (mg B/L)	0.032 to 0.233	NA	NA	ECCC 2021h
Water, from landfill leachate concentrations (mg B/L)[a]	0.11 to 0.65	15	2008 to 2013	Conestoga-Rovers and Associates 2015

Medium and units	PEC range	Number of samples (n=)	Sampling period	Reference
Soil (mg B/kg dw), from biosolids application	1.97	NA	2011 to 2018	ECCC 2019

Abbreviations: PEC, predicted environmental concentration; NA, not applicable

[a] Assuming a default dilution factor of 10 once wastewater effluent has reached the receiving environment

7.3.2.10 Rubber manufacturing

Less than 4 rubber manufacturing companies imported between 10 to 1,000 tonnes of boric acid precursors yearly into Canada from 2009 to2012 (CBSA 2013), typically for use as a 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 effluents to the receiving environment directly (direct dischargers) or indirectly via wastewater systems (indirect dischargers).

EACs were calculated for direct dischargers and indirect dischargers (Table 7-9), assuming that the maximum yearly quantity of boric acid imported into Canada for this sector is used at a single facility. PECs for indirect dischargers are obtained by adding the background concentration of 0.031 mg B/L and the concentration from down-the-drain releases (0.0008 to 0.202 mg B/L). PECs for direct dischargers are obtained by adding the background concentration of 0.031 mg B/L. Further details are available in ECCC (2021h).

Table 7-9. Summary of EACs and PECs for direct and indirect dischargers as a result of rubber manufacturing

Type of dischargers	EAC range (mg B/L)	PEC range (mg B/L)	Reference
Direct dischargers	0.00001 to 0.038	0.057 to 0.32	ECCC 2021h
Indirect dischargers	0.032 to 0.26	0.032 to 0.26	ECCC 2021h

Abbreviations: EAC, estimated environmental concentration; PEC, predicted environmental concentration

7.3.2.11 Surface finishing

Boric acid precursors are imported into and used in Canada by surface finishing facilities (that is, electroplating) (Environment Canada 2009a, 2013c; CBSA 2013) to clean substrate surfaces 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 to 100 tonnes (Environment Canada 2013c). The upper end value of 100 tonnes was used to estimate the largest quantity used at a single facility discharging its treated wastewater to an off-site wastewater 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 concentration, a conservative aquatic PEC range of 0.13 to 0.33 mg B/L is obtained for this sector. Further details are available in ECCC (2021h).

7.3.2.12 Fibreglass insulation manufacturing

Large quantities of boric acid precursors (1,000 to 50,000 tonnes) were imported annually, used, or purchased by insulation fibreglass manufacturers in Canada from 2008 to 2012 (CBSA 2013; Environment Canada 2013c). The substances are used as flux to lower glass batch melting temperatures (Borax 2024a), increase mechanical strength and drawing quality (Woods 1994), impart decompressibility (ETI Products 2018), and increase product insulation performance (Borax 2024b).

Impacts on vegetation from air emissions of boric acid precursors have 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 include chlorosis and dark intercostal necrotic lesions of leaves (Temple et al. 1978; Eriksson et al. 1981). Emissions from the glass melting process can be in the form of particulates (boron oxides) or gaseous (as boric acid) (US EPA 1995; NPI [modified 2004]), 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 B/L) and foliage (a maximum concentration of 989 mg B/L) 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 foliage and from soluble boron in soil (Temple et al. 1978). Boric acid precursors were eliminated from the manufacturing process at this Canadian facility in 1973, ending emissions of boric acid precursors from 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 air emissions and the 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). This scenario was developed for a large Canadian facility using conservative emission rates and the AERMOD program, resulting in a maximum steady-state PEC_{added} in soil of 1.3 mg B/kg on the basis of continuous release for 100 years (Environment Canada 2014d). Further details are available in ECCC (2021h).

Additionally, elevated boron concentrations (up to 114 mg B/kg for total boron and up to 26.4 mg B/kg for hot-water-soluble boron) have been observed in soil samples collected on the property of one facility that uses borax (Environmental Site Registry 2025). These elevated concentrations were hypothesized to be related to the presence of outdoor stockpiles of crushed glass (cullet) on the property or to releases linked to a loading dock used to accept raw materials including borax (Environmental Site Registry 2025). Elevated soil concentrations observed on site are, however, believed to be limited to property boundaries.

7.3.2.13 Generic activities

Boric acid is also 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 small industrial users comprises various uses (for example, arts and crafts materials and toys, DIY products including adhesives and sealants, automotive maintenance, home maintenance, paints and coatings, electrical equipment, uses in metallurgy and in laboratories), with each category having an annual cumulative import quantity below 10,000 tonnes (PECs were not estimated for these uses but are expected to be lower than those from large users due to the dispersive use of smaller quantities).

The category of large industrial users comprises 2 main sectors that have an annual cumulative import quantity of more than 10,000 tonnes of boric acid precursors: agriculture products manufacturing (for example, fertilizers and pesticides) and construction products manufacturing (for example, fibreglass insulation, cellulose insulation, engineered wood products, and gypsum board). Boric acid and precursors are used as flame retardant in cellulose insulation and engineered wood products (LeVan and Tran 1990; Borax 2024b). Boric acid is also added during the manufacture of gypsum board to improve manufacturing processes, increase strength, and enhance resistance to fire (Borax 2024d).

A total of 53 facilities were identified as large users on the basis of import data obtained from the CBSA (CBSA 2013) and through a CEPA section 71 survey (Environment Canada 2009a). The facilities were further divided into 3 quantity groups:

- Group I (21 facilities): yearly use quantity per facility = 1 to 100 tonnes
- Group II (28 facilities): yearly use quantity per facility = 100 to 1,000 tonnes
- Group III (4 facilities): yearly use quantity per facility = 1,000 to 10,000 tonnes

Conservative EACs were calculated for indirect discharges to the environment from these activities by combining the daily release of boron, which is based on the maximum use quantity of boric acid precursors selected for each group, with daily dilution water volumes. Calculated EACs ranged from 0.00012 to 0.5 mg B/L, resulting in PECs ranging from 0.032 to 0.73 mg B/L when background concentrations and down-the-drain releases were added. Further details are available in ECCC (2021h).

7.4 Characterization of ecological risk

The approach taken in this ecological assessment was to examine assessment information and develop proposed conclusions using a weight-of-evidence approach and precaution. Evidence was gathered to determine the potential for boric acid, its salts and its precursors to cause harm in the Canadian environment. Lines of evidence considered include those evaluated in this assessment that support the characterization of ecological risk in the Canadian environment. Reliable secondary or indirect lines of evidence are considered when available, including classifications of hazard or fate characteristics made by other regulatory agencies. The potential for cumulative effects was considered in this assessment by examining cumulative exposures to the moiety of boric acid.

7.4.1 Risk quotient analysis

Risk quotient (RQ) analyses were performed by comparing the various estimates of exposure (PECs; see the Ecological Exposure Assessment section) with ecotoxicity information (PNECs; see the Ecological Effects Assessment) to determine whether there is potential for ecological harm in Canada. RQs were calculated by dividing the PEC by the PNEC for relevant environmental compartments and associated exposure scenarios.

While the majority of RQs are below 1, PNEC exceedances were identified in the aquatic environment for the metal ore mining sector and oil sands extraction and processing sector (Table 7-10). For the metal ore mining sector, RQs were low (that is, below 0.6) for 108 sites, while moderately high RQs of 0.79 to 0.87, 0.02 to 0.95, and 0.01 to 0.86 were calculated for 3 sites (Sites 1, 3, and 7, respectively). Elevated RQs of 1.9 to 13.3 were calculated at one milling site for all measurements (n=22) at the exposure area over a 10-year period (from 2010 to 2019). This milling facility has applied measures to reduce boron concentration in effluents and receiving water since 2013. As a result, boron concentrations in the receiving surface water decreased by nearly half between 2016 and 2019 compared with their pre-2013 levels (ECCC 2021c); however, RQs remained relatively high (1.9 to 8.7), which is indicative of potential ecological concern associated with aquatic releases of boric acid at this location.

With respect to the oil sands extraction and processing sector, the upper range PEC value of 1.72 mg B/L may reasonably be considered as an outlier (see section 7.3.2.5). The 95th percentile PEC value was therefore used for comparison with the PNEC value, resulting in an RQ of 0.11.

For the pulp and paper sector, the highest RQ is 1.1, estimated from the highest boron effluent concentration at one site. The mean RQ for the site is 0.29. The next highest estimated RQ is 0.69. Lower estimates for the RQs may be derived with further refining of the pulp and paper exposure scenario, although this was not deemed necessary at this time.

Table 7-10. Summary of RQs obtained for different media and exposure scenarios for boric acid

Sector	Medium	PNEC water (mg B/L); PNEC$_{added}$ soil (mg B/kg)	Range of PECs[a] water (mg B/L); PEC$_{added}$ soil (mg B/kg)	Range of RQs
Power generation	Water	1.5	0.786 to 1.0	0.52 to 0.67
Power generation	Soil	6.08	0.322	0.053
Metal ore mining[b]	Water	1.5	Negligible to 20	up to 13.3
Smelting and refining	Water	1.5	Negligible to 1.17	up to 0.78
Coal mining	Water	1.5	0.004 to 0.061	up to 0.04
Oil sands extraction and processing	Water	1.5	0.0001 to 1.7; 0.16[c]	up to 1.13; 0.11[d]
Oil sands extraction and processing	Soil	6.08	0.92	0.15
Agriculture	Water	1.5	<0.05	0.03
Pulp and paper	Water	1.5	0.011 to 1.6	0.007 to 1.1
Wastewater and down-the-drain releases	Water	1.5	0.032 to 0.233	0.02 to 0.16
Waste management (landfill leachate)	Water	1.5	0.11 to 0.65	0.07 to 0.43
Biosolids application	Soil	6.08	1.97	0.33
Rubber manufacturing	Water	1.5	0.032 to 0.32	0.02 to 0.21
Electroplating	Water	1.5	0.127 to 0.328	0.08 to 0.21
Fibreglass manufacturing	Soil	6.08	1.3	0.21
Generic scenarios	Water	1.5	0.032 to 0.733	0.02 to 0.49

Abbreviations: PNEC, predicted no-effect concentration; PEC, predicted environmental concentration; RQ, risk quotient

[a] Calculated on the basis of dissolved boron concentrations when available.

[b] “Metal ore mining” activities can include both ore extraction via open-pit or underground mining and ore processing at a milling facility that is commonly referred to as a mill. The site with consistent RQ > 1 is a milling site that processes a range of ores and feeds.

[c] PEC was derived on the basis of the 95th percentile dissolved boron concentration calculated for “test” stations (n=590) sampled as part of RAMP [modified 2018], where a single dissolved boron concentration value of 1.7 mg/L above the PNEC was measured.

[d] RQ was calculated using a PEC on the basis of the 95th percentile dissolved boron concentration for “test” stations.

7.4.2 Consideration of lines of evidence and conclusion

To characterize the ecological risk of boric acid, its salts and its precursors, technical information for various lines of evidence was considered (as discussed in the relevant sections of this report) and qualitatively weighted. The key lines of evidence supporting the assessment conclusion are presented in Table 7-11, with an overall discussion of the weight of evidence provided in section 7.4.3. The level of confidence refers to the combined influence of data quality and variability, data gaps, causality, plausibility, and any extrapolation required within the line of evidence. The relevance refers to the impact the line of evidence has when determining the potential to cause harm in the Canadian environment. Qualifiers used in the analysis ranged from low to high, with the assigned weight having 5 possible outcomes.

Table 7-11. Weighted lines of key evidence considered in order to determine the potential for boric acid, its salts and its precursors to cause harm in the Canadian environment

Line of evidence	**Level of confidence**[a]	**Relevance in ecological assessment**[b]	**Weight assigned**[c]
Environmental fate and behaviour (ionic nature)	High	High	High
Persistence in the environment	High	Moderate	Moderate to high
Bioaccumulation in organisms	High	Low	Moderate
Mode of action	High	Low	Moderate
PNEC for freshwater organisms	High	High	High
$PNEC_{added}$ for soil-dwelling organisms	High	High	High
PECs based on monitoring data for concentrations in surface water	High	High	High
PECs based on monitoring data for concentrations in industrial and wastewater effluents	Moderate	High	Moderate to high
PECs based on model data for concentrations in water	Moderate	High	Moderate to high
PECs based on monitoring data for concentrations in soil	High	High	High
PECs based on model data for concentrations in soil	Moderate	High	Moderate to high
RQ(s) for water in coal-fired power generation, metal ore mining, base metals and precious metals smelters, coal mining, oil sands extraction and processing, and pulp and paper manufacturing	High	High	High

Line of evidence	Level of confidence[a]	Relevance in ecological assessment [b]	Weight assigned[c]
RQ(s) for water in agriculture, wastewater, down-the-drain releases, biosolid application and waste management, rubber, surface finishing, fibreglass insulation manufacturing, and generic scenarios	Moderate	Moderate	Moderate
RQ(s) for soil	Moderate	High	Moderate to high

[a] Level of confidence is determined according to data quality, data variability, and data gaps (that is, are the data fit for purpose).
[b] Relevance refers to the impact of the evidence on the ecological assessment.
[c] Weight is assigned to each line of evidence according to the overall combined weights for level of confidence and relevance in the ecological assessment.

7.4.3 Weight of evidence for determining potential to cause harm to the Canadian environment

Once released into the environment, many different salts or precursors of boric acid will dissociate or release via relevant transformation pathways to a common moiety of concern, boric acid. Boric acid is expected to be persistent in water, soil, and sediment, resulting in potential exposure to aquatic and terrestrial organisms. Sediments are not anticipated to be a significant sink for boric acid in freshwater ecosystems because of its high water solubility and weak complexation to common cations. Boron is considered to be an essential element in most plants and some animals. 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 it does not biomagnify in the environment.

This assessment of boric acid, its salts and its precursors examined exposures from a wide range of potential sources (see section 4.2) that could contribute to loadings of boric acid in the environment, including: 1) coal-fired power generation stations, 2) metal ore mining, 3) base metals and precious metals smelting and refining, 4) coal mining, 5) oil sands extraction and processing, 6) oil and gas extraction, 7) agriculture, 8) pulp and paper manufacturing, 9) wastewater systems and waste management, 10) rubber manufacturing, 11) surface finishing, 12) fibreglass insulation and manufacturing, and 13) generic activities. RQ analyses were conducted for 12 of the 13 sectors or activities (that is, excluding the oil and gas extraction sector) to determine the potential for ecological harm from releases of boric acid to the environment.

The RQ analyses indicate that anthropogenic releases of boric acid, its salts and its precursors are not expected to result in concentrations of boric acid at levels of concern in the Canadian environment (water and soil) for most sectors or activities, including: coal-fired power generation stations, base metals and precious metals smelting and refining, coal mining, agriculture, wastewater systems and waste management, rubber manufacturing, surface finishing, fibreglass insulation and manufacturing, and generic scenarios (see section 7.4.1). The maximum RQs for these sectors are all well below 1 (that is, below 0.8 and mostly below 0.5).

For the oil sands extraction and processing sector, elevated boron concentrations (up to 196 mg B/L) have been reported in OSPW from both surface mining and underground (in situ) operations and in coke leachate (up to 749 mg B/L), which are stored in tailing and storage ponds. Releases of boron to the aquatic environment may occur as a result of surface water runoff from mining areas and seepage from tailing ponds and OSPW storage ponds (Pollet and Bendell-Young 2000; Frank et al. 2014). Estimated RQs for multiple monitoring stations situated on the Athabasca River and many of its tributaries from the RAMP ([modified 2018]) and JOSM ([modified 2018]) are generally below 1. Although an upper end RQ of 1.1 was calculated for one measurement at one location, the median or the second highest estimated RQ is well below 1 (less than 0.13), suggesting that the PNEC exceedance at this site may be transitory. The information available indicates that boron releases for this sector may be considered unlikely to be causing ecological harm.

There was limited evidence to indicate that boron releases from the pulp and paper sector pose an ecological concern to the Canadian aquatic environment at current levels. For the pulp and paper sector, the exposure scenarios considered multiple sources of exposure data, including from a recent study sponsored by the National Council for Air and Stream Improvement (NCASI 2020) and effluent concentrations reported to the PPER and other sources (UBC 1996; NCASI 2006; Kovacs et al. 2007; Martel et al. 2010; MDDEP 2010b). The data sets collected from mills were representative of different mill process categories, wood fibre sources, and multiple regions across Canada. The data sets also included both total and dissolved boron concentrations, thereby increasing confidence in the PECs and RQs calculated for this sector. One facility had one measurement with an RQ of greater than 1 (that is, 1.1), while the median RQ was below 1 (0.29), suggesting that the PNEC exceedance at this site may be transitory. The information available indicates that boron releases for this sector may be considered unlikely to be causing ecological harm.

For the metal ore mining sector in Canada, information on boron concentrations in receiving surface waters or in effluents is available for 115 facilities, approximately 74% of mining sites in operation during 2003 and 2020 (EEM 2021). Boron concentrations were less than or equal to 0.5 mg B/L for 108 sites, indicating that anthropogenic releases of boric acid, its salts and its precursors are not expected to result in concentrations of boric acid at levels of concern in the Canadian environment from these facilities. The exposure analysis focused on the 7 sites that showed boron concentrations of above 0.5 mg B/L in the exposure areas. Of the 7 facilities analyzed, one location or area of concern for aquatic organisms was identified for the metal ore mining sector, with high RQs for that site (an ore milling facility) ranging from 1.9 to 13.3 at the exposure area over a 10-year period (2010 to 2019). The RQs remained relatively high (1.9 to 8.7) even after the facility applied measures to reduce boron concentration in effluents and receiving water beginning in 2013. RQs of up to 0.87, 0.95, and 0.86 were also calculated for 3 other sites within this sector, including one mine, one combined mine and smelter site, and one uranium mill. On the basis of these findings, a small number of facilities within the metal ore mining sector may release boron to an extent that causes or has the potential to cause ecological concern.

This information indicates that boric acid, its salts and its precursors have the potential to cause ecological harm in Canada.

7.4.4 Sensitivity of conclusion to key uncertainties

Boric acid is well characterized 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 with respect to effects on sediment organisms. Experimental difficulties in achieving and maintaining exposure concentrations within sediment were noted, owing to the tendency of boric acid to partition back into the water phase. Given the fact that the sediment NOEC values for spiked water tests were much higher 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 $PNEC_{added}$. The added risk approach assumes that only the anthropogenic added fraction of boric acid contributes to risks, thereby ignoring the possible contribution of ambient background concentration to hazardous effects. Although the contribution of ambient background concentration to hazardous effects is anticipated to be low, conservative assumptions (for example, no loss via runoff, leaching, or uptake by plants) were used when generating model soil PEC_{added} as a precaution. A rich data set of high quality, chronic soil toxicity studies for 23 species, including many boreal species found in Canada, was used to derive the soil $PNEC_{added}$ using an SSD approach. The data set met the species coverage requirements described in domestic (CCME) and international (MERAG) guidance. Overall, uncertainty in the ecological effects data is considered to be low.

Data on imported quantities from the CBSA and CIMT were used to supplement findings from surveys issued pursuant to section 71 of CEPA and voluntary stakeholder engagement in order to characterize the sectors that have the largest involvement with boric acid precursors. Importers were assigned to a sector using assumptions about the importer’s primary activity, which were made on the basis of publicly available information or by correlation with responses to surveys or voluntary stakeholder engagement. An additional uncertainty arises from the fact that the CBSA and CIMT data are organized by HS codes, which in several cases describe groups of substances (for example, 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 needed to be converted to boron equivalents for comparison with the PNECs, it was conservatively assumed that all HS code-based import quantities would be treated as boric acid. Among the major commercial boron-containing substances (for example, borax pentahydrate, borax decahydrate), boric acid has the highest boron content (17.5%), while the majority of other boric acid precursors are 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 system or surface water body. If the maximum modelled aquatic PEC values were added for multiple sectors, the resulting combined PEC could potentially exceed the aquatic PNEC. However, on the basis of the CBSA data (which contain user locations), voluntary stakeholder engagement, and responses to surveys issued pursuant to section 71 of CEPA, it was determined that such “combined release” would be unlikely. Some uncertainty remains, with the potential for the relocation of users or introduction of new users resulting in combined releases. However, from a probabilistic standpoint, it appears to be a rare occurrence for multiple users to all be at the maximum of the exposure distribution for their sectors at the same time and place. Additionally, the exposure calculations and assumptions were realistic but conservative.

Aquatic concentrations of boron in the receiving environment downstream from effluent discharge points were available for approximately 74% of mining sites. While this does not present a full picture of boron releases from Canada’s mining sector, the available data are recent and are considered representative. One mill site showed a high potential for ecological harm and 3 sites had RQs approaching levels of concern.

When it was not specified whether the concentrations reported were for total boron or dissolved boron, it was assumed that the concentrations were for dissolved boron in order to remain conservative (that is, assuming high bioavailability). However, the ecological assessment conclusions do not take this assumption into account because dissolved and total boron measurements are generally almost identical.

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 a statistical outlier because the 95th percentile and median values were found to be well below the aquatic PNEC. This was only the case for this sector, and the outlier was deemed not to have sufficient 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 outliers.

Overall, uncertainties in the ecological exposure characterization may be greater than the ecological effects characterization. Conservative assumptions were applied to most of the exposure scenarios in order to minimize the possibility of a false-negative risk determination.

8. Potential to cause harm to human health

8.1 Health effects assessment

Several national and international organizations have reviewed the health effects of exposure to boric acid, its salts and its precursors (US EPA 2004, 2015a; EU 2007; ATSDR 2010; EFSA 2013; ECHA 2014). Boric acid, its salts and its precursors were also reviewed by the Natural and Non-prescription Health Products Directorate (Health Canada 2007), the Health Canada Pest Management Regulatory Agency (PMRA) (Health Canada 2012, 2016), and the Health Canada Water and Air Quality Bureau (Health Canada 2023a). These existing assessments were used to inform the health effects section for this assessment.

8.1.1 Essentiality in humans

The essentiality of boron has been proven in most plants and in some animals (see section 7.1). There is some evidence that boron is involved in calcium regulation in animals, which may have implications for bone metabolism (US EPA 2015a). The World Health Organization (WHO 1996) classifies boron as “probably essential”; however, there are insufficient data to confirm essentiality in humans (ATSDR 2010; Health Canada 2012, 2023a; ECHA 2014; US EPA 2015a).

8.1.2 Toxicokinetics

The toxicokinetics of boric acid is similar in rats and humans (ANSES 2012; Health Canada 2012; ECHA 2014; US EPA 2015a). Boric acid and borates are rapidly and near completely absorbed following oral ingestion (US EPA 2004, 2015a; ATSDR 2010; ANSES 2012; ECHA 2014), and absorption ranged from 64% to 98% in experimental animals (rats, rabbits) (Health Canada 2023a). Inorganic borates are hydrolyzed to the un-ionized form of boric acid (pKa of 9.2) in the acidic environment of the gut and are then absorbed primarily via passive diffusion into systemic circulation (EFSA 2013; Health Canada 2023a). In addition, boron can enter systemic circulation following inhalation exposure in rats and humans (US EPA 2004, 2015a; ATSDR 2010; Health Canada 2023a). A 100% inhalation absorption rate as worst-case assumption was applied in this assessment, which is consistent with risk assessments of boron compounds by ATSDR (2010), ECHA (2014), and the US EPA (2015a).

A dermal absorption value was estimated on the basis of results from an *in vivo* human study by Wester et al. (1998a). This study was used by the European Commission Scientific Committee on Consumer Safety (SCCS 2010a, 2010b) and Health Canada’s PMRA (2016) to establish default dermal absorption values for boron. 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 octaborate tetrahydrate (10%) in aqueous solution. Both pre-treatment urine from days 1 to 4 and post-treatment urine from up to day 17 were collected. On day 5, the test chemical was applied to the back area of individuals. Volunteers were instructed to wear a T-shirt to protect the dosed area. The chemical remained on the skin for 24 hours, at which point the remaining chemical was removed via skin washes. In this study, the mean percentage absorbed (standard deviation) was reported to be 0.226% (± 0.125), 0.210% (± 0.194), and 0.122% (± 0.108) for boric acid, borax, and disodium octaborate tetrahydrate, respectively (Wester et al. 1998a). Chemical losses to outside clothing and bedding were not corrected in the reported study results or by the SCCS (2010a, 2010b) in their assessment. On the basis of the chemical losses that were recovered on the T-shirt, Health Canada (2016) calculated a corrected dermal absorption value of 2% to 4%.

A more recent study assessed *in vitro* dermal absorption of dimethylamine borane using fresh human skin samples obtained from elective surgery (Mathews et al. 2014). Flow-through diffusion cells using skin samples (surface area=0.64 cm^2) were treated with 0.054 and 0.54 mg radiolabelled [^{14}C]dimethylamine borane in ethanol (6 cells/dose). The treatments were left to perfuse for 24 hours. On average, 41% of the applied dose of dimethylamine borane was absorbed through the skin, while 2% to 3% remained in the skin discs. However, the recovery of the radiolabel in this study was low (69% and 78% for low and high doses, respectively). In addition, dose suspensions were prepared using ethanol as a vehicle, which is a known skin penetration enhancer (Lachenmeier 2008 as cited in Health Canada 2020a).

Due to limitations in the key human *in vivo* dermal absorption study (Wester et al. 1998a), including a low mass balance recovery and exclusion of skin bound residues, a dermal absorption of 10% was determined by Health Canada (2016). The current assessment adopted the same dermal absorption value of 10% as Health Canada (2016), while also considering the *in vitro* dermal absorption study for dimethylamine borane in the weight of evidence (Mathews et al. 2014). This value accounts for study limitations and different product formulations, as well as for the use of a single dermal absorption value for all forms of boron.

In addition, this assessment uses the highest reported permeability coefficient (Kp, 5.0×10^{-4} cm/h) from Wester et al. (1998b) to estimate dermal exposure in infinite dose scenarios (for example, swimming in pools). Wester et al. (1998b) studied the *in vitro* percutaneous absorption of boric acid (0.05% to 5%), borax (5%), and disodium octaborate tetrahydrate (10%) through human skin. The study reported Kp values ranging from 1.4×10^{-6} to 5.0×10^{-4} cm/h.

Following absorption, boron is distributed rapidly and uniformly throughout body fluids and soft tissues (liver, kidney, muscle, colon, brain, testis, epididymis, seminal vesicles, prostate, and adrenals) (US EPA 2004; ATSDR 2010; Health Canada 2023a). Steady state boron concentrations are reached within 3 to 4 days (ATSDR 2010; Health Canada 2023a). Boron does not accumulate in soft tissues above plasma concentrations but does accumulate in bone, with concentrations 2 to 3 times higher in bone than in soft tissues (US EPA 2004, 2015a; ATSDR 2010; Health Canada 2023a). There is evidence that boron can cross the placenta, and it has been detected in placental and umbilical cord blood in humans (Health Canada 2023a). Additionally, in a study of mother-infant pairs in northern Argentina and Chile, boron was found to partition into human milk (Harari et al. 2012).

Boric acid is the predominant form at physiological pH (7.35 to 7.45) (US EPA 2004; EFSA 2013; US EPA 2015a). Boric acid does not appear to be metabolized in animals or humans due to the high energy level required (523 kilojoules per mole) to break the boron-oxygen bond (US EPA 2004; EFSA 2013; ECHA 2014; Health Canada 2023a).

Boric acid is excreted unchanged, primarily via urine (US EPA 2004; Health Canada 2023a), regardless of the route of exposure (EFSA 2013). In humans, approximately 90% of ingested boric acid is excreted in the urine (US EPA 2004, 2015a; EFSA 2013; ECHA 2014; Health Canada 2023a). Only a small fraction is excreted in the feces (2% to 5%) (US EPA 2015a). Therefore, the rate of boric acid elimination is largely dependent on renal clearance (US EPA 2015a; Health Canada 2023a). Since the glomerular filtration rate in rats (163 mL/hour/kg or 2.72 mL/min/kg) is approximately 4 times higher than in humans (41 mL/hour/kg or 0.68 mL/min/kg) when corrected for body weight, the corresponding renal clearance rate in rats is approximately 4 times faster (US EPA 2004; Health Canada 2012; EFSA 2013). Pregnancy increases renal clearance rates in humans and rats by 50% and 21%, respectively (Health Canada 2023a); therefore, it is expected that boron will be cleared more rapidly in pregnant individuals than in their non-pregnant counterparts (US EPA 2004; Health Canada 2012). The plasma half-life of boron in rats and humans is similar, ranging from 14 to 19 hours and 10 to 21 hours, respectively (Health Canada 2012).

Concentrations of boron in blood or urine are adequate biomarkers to quantify exposure to boron (ATSDR 2010). Urinary boron concentrations are considered a more sensitive indicator of boron intake than blood since boron tissue concentrations are homeostatically regulated mainly through renal secretion (Sutherland et al. 1998; Khaliq et al. 2018).

8.1.3 Systemic health effects

Animal studies

Animal studies that were reviewed for this assessment are limited to those selected by other organizations to inform their points of departure (PODs). For this assessment, a literature search was conducted on literature published between 2019 and 2021, which encompasses the year prior to the most recent assessment on boric acid, its salts and its precursors. The results from this literature search did not impact the risk characterization from previous assessments (that is, it did not suggest different critical endpoints or lower PODs).

Heindel et al. (1992) assessed the developmental toxicity of boric acid administered in diet (0, 13.6, 28.5, or 57.7 mg B/kg bw/day) in time-mated female Sprague-Dawley rats (26 to 28/dose) from gestational days (GDs) 0 to 20. Additionally, a group of rats received 94.3 mg B/kg bw/day on only GDs 6 to 15 (that is, post-implantation). There were no maternal treatment-related effects at all doses tested. A dose of 94.3 mg B/kg bw/day caused a significant increase in prenatal mortality. A significant decrease in fetal body weight occurred in all dose groups compared with the controls. Fetal malformations and variations of the axial skeleton (short rib XIII and wavy ribs, respectively) occurred at 13.6 mg B/kg bw/day and above. A lowest-observed-adverse-effect level of 13.6 mg/kg bw/day, which was based on a decrease in fetal body weight in the absence of maternal toxicity, was selected by the study authors. A no-observed-adverse-effect level (NOAEL) was not identified.

A follow up study by Price et al. (1996) was conducted to establish a NOAEL for developmental toxicity. The study consisted of 2 phases: phase I evaluated effects of prenatal exposure, whereas phase II included a postnatal follow-up portion to evaluate the potential reversibility of body weight effects and whether skeletal anomalies persisted during the postnatal period. In phase I of the study, time-mated female Sprague-Dawley rats (60/dose) were administered boric acid in diet (0. 3.3, 6.3, 9.6, 13.3, or 25.0 mg B/kg bw/day) from GDs 0 to 20. No maternal toxicity was observed during treatment. At GD 20, there was a significant reduction in fetal body weights at 13.3 and 25.0 mg B/kg bw/day compared with the control group. At the same dose levels, there was an increased occurrence of skeletal abnormalities (short rib XIII malformation and wavy rib variation) in comparison with controls. In phase II, female rats received boric acid in diet from GDs 0 to 20 (exposure terminated at birth) and were allowed to deliver and rear their litters until postnatal day (PND) 21. From PNDs 0 to 21, there was no difference in offspring bodyweight compared with the control. Similarly to phase I of the study, there was a significant increase in skeletal abnormalities at 13.3 and 25.0 mg B/kg bw/day. There was a statistically significant increase in the percentage of pups per litter with short rib XIII at the highest dose tested (25.0 mg B/kg bw/day). Health Canada (2012, 2023a) selected a developmental NOAEL of 9.6 mg/kg bw/day from this study.

Weir and Fisher (1972) conducted a series of repeated-dose studies in dogs. According to Health Canada's PMRA assessment (Health Canada 2012, 2016), many discrepancies were noted in the published dog studies when these were compared with the original study data (also coordinated or supervised by Weir). Where possible, and as was previously done in the PMRA assessment, this assessment relies on the original study data.

In the 90-day studies, beagle dogs (5/sex/dose/substance) were administered boric acid or borax in diet at 0, 0.46, 4.2, and 35 or at 0, 0.4, 5.0, and 46.2 mg B/kg bw/day, respectively. Decreased absolute and relative testis weight was observed at 4.2 mg B/kg bw/day and at 0.4 mg B/kg bw/day in males administered boric acid and borax, respectively. All males from the mid-dose groups (4.2 mg B/kg bw/day for boric acid and 5.0 mg B/kg bw/day for borax) showed artifactual distortion of the tubules in the outer third of the testis. In addition, the males from these dose groups had an increased proportion of solid epithelial nests in the thyroid. Severe testicular atrophy and increases in interstitial tissue were observed in all males at the highest doses tested (35 mg B/kg bw/day for boric acid and 46.2 mg B/kg bw/day for borax). Complete degeneration of the spermatogenic epithelium in 4/5 dogs was observed in both high-dose groups. Additional effects at 46.2 mg B/kg bw/day included the breakdown of red blood cells and decreased brain weight (Weir and Fisher 1972 as cited in Health Canada 2012). Health Canada (2012) selected a provisional NOAEL of 4.2 mg B/kg bw/day for males.

In the two-year (104 weeks) toxicity study by Weir and Fisher (1972), beagle dogs (4/sex/dose/substance) were administered borax or boric acid in diet at 0, 1.4, 3.0, and 8.8 or 0, 1.6, 3.6, and 9.4 mg B/kg bw/day, respectively. The sacrifice schedule was as follows: 1/dose/substance at 52 weeks, 2/dose/substance at 104 weeks, and 1/dose/substance after a 13-week recovery period. At 2 years, atrophied tubules in the testis were observed in one male administered boric acid and in 2 males administered borax at the lowest doses tested (1.4 mg B/kg bw/day and 1.6 mg B/kg bw/day, respectively). At the highest dose tested for boric acid, testicular atrophy was observed in one dog sacrificed after 104 weeks of exposure. There was a general increase in the severity and number of thyroid effects, primarily epithelial nests, after 2 years of exposure (Weir and Fisher 1972 as reported in Health Canada 2012). From this study, a provisional NOAEL of 3.0 mg B/kg bw/day was identified by the PMRA on the basis of reproductive toxicity in males (Health Canada 2012).

The most recent assessment on boron covers the literature up to 2018 (Health Canada 2023a). Since then, several repeated-dose toxicity studies on boron have been published using rodent models (Aktas et al. 2020; Watson et al. 2020; Wang et al. 2021). These studies have been reviewed and are described below.

Watson et al. (2020) conducted a developmental toxicity study that assessed pre- and postnatal exposure to boric acid. Time-mated female Sprague-Dawley rats (8/dose) were administered boric acid at 0, 5, 10, or 20 mg B/kg bw/day via gavage from GDs 6 to 21. Following birth, pups were administered the same dose as their respective dams from PNDs 1 to 28. Dams were not dosed post-birth to prevent lactational transfer of boron to pups. Litters were standardized to 8 per litter on PND 4. Plasma boron concentrations were monitored in pups from PNDs 4 to 28 and were found to increase in a dose-proportional manner. No maternal mortality or toxicity was observed at any of the doses tested. A low incidence of umbilical hernias occurred in pups from the 20 mg B/kg bw/day group, which resolved itself by the end of the study (PND 30). There was a significant reduction in postnatal weight gain in pups exposed to 20 mg B/kg bw/day (23% weight reduction compared with controls at PND 28). The authors identified a NOAEL of 10 mg B/kg bw/day on the basis of reduced postnatal pup weight gain at 20 mg B/kg bw/day.

Wang et al. (2021) investigated the effects of boron exposure on reproduction in male rats. Adult male Sprague-Dawley rats (17/dose) were administered borax at 0, 25, 50, or 100 mg B/kg bw/day via gavage for 28 days. After the exposure period, male rats

(5/dose) were mated with untreated female rats in order to assess fertility. The mating and gestation process was repeated 10 times in 7-day intervals. The remaining male rats (12/dose) were anaesthetized, and levels of testicular enzymes, testicular hormones, plasma hormones, and plasma cytokines were analyzed. The gestation rate and mean number of fetuses were unaffected by boron exposure; however, the proportion of live fetuses was significantly reduced at 50 and 100 mg B/kg bw/day for the first 2 mating periods in comparison with the control group. There were no significant changes in testes and epididymides weight, although male rats in the highest dosing group (100 mg/kg bw/day) showed a significant decrease in heart to body weight ratio. Boron content in the testis did not change significantly between dosing groups. Concentrations of plasma follicle stimulating hormone and certain testicular hormones (estrone, estradiol, estriol, testosterone, cortisol, and androstenedione) were increased in a dose-dependent manner. Androstenedione and estradiol levels were significantly increased at all dose levels compared with the control group. Boron exposure did not cause significant changes in luteinizing hormone levels. A no-observed-effect level could not be identified for this study since changes in hormone levels were noted at all dose levels.

Aktas et al. (2020) assessed the effects of boric acid on oxidative stress in testicular tissue and on sperm quality parameters. Adult male Swiss Albino mice (10/dose/duration) were administered boric acid at 0, 115, 250, or 450 mg B/kg bw/day via gavage for either 4 or 6 weeks. At the end of the exposure period, mice were euthanized for post-mortem analysis. Both seminal vesicles and testis were weighed. Oxidative stress markers (malondialdehyde [MDA], superoxide dismutase [SOD], catalase [CAT], and glutathione [GSH]) were isolated from testicular tissue samples, and their levels were measured. Additionally, sperm samples were taken from the cauda epididymis in order to measure sperm cell motility, viability, membrane integrity, and DNA integrity. There was no significant change in testis weight at all doses tested. Any significant changes observed in seminal vesicle weight were not dose-dependent. Sperm motility was reduced at 450 mg/kg bw/day after 4 weeks and at both 250 and 450 mg/kg bw/day after 6 weeks. Live sperm rate and membrane integrity were significantly lower than controls at all doses tested; however, these parameters did not decrease in a dose-dependent manner. DNA damage increased with dose after 6 weeks of exposure only. There was an increase in MDA and a decrease in GSH after 4 or 6 weeks of exposure. Reductions in SOD activity were significant after 6 weeks of exposure, and there were no significant changes in CAT activity at any dose tested. Given the limited examinations in this study, no PODs were selected.

In vitro and *in vivo* data did not indicate any concern for genotoxicity or carcinogenicity (Health Canada 2012, 2023a; EFSA 2013). Available epidemiology studies do not suggest an association between boron exposure and cancer in humans (Health Canada 2012, 2023a; US EPA 2015a). Overall, there is consensus among previously conducted risk assessments that there is no evidence to suggest that boron is genotoxic or carcinogenic (Health Canada 2012; EFSA 2013; US EPA 2015a; Health Canada 2023a).

Human studies

An acute and weekly supplementation study using sodium tetraborate decahydrate capsules was conducted on 8 male[7] volunteers (Naghii et al. 2011). On day 0, blood was drawn at 8:00 a.m., followed by ingestion of a placebo with breakfast. Similarly, on day 1, blood was drawn at the same time; however, this was followed by ingestion of a capsule containing 10 mg boron as sodium tetraborate (0.14 mg B/kg bw/day, assuming a body weight of 70 kg) with breakfast. On both days 0 and 1, additional blood samples were collected every 2 hours for 6 hours. Males were asked to consume the boron supplements every morning with breakfast for the remainder of the week. On day 7, blood was collected again at 8:00 a.m. All plasma samples were analyzed for boron concentration, hormones, and inflammatory biomarkers. Concentrations of sex hormone binding globulin was significantly lower at 2, 4, and 6 hours following boron consumption on day 1. Among the inflammatory biomarkers, there was a significant decrease in tumour necrosis factor alpha (TNF-α) within 6 hours of consuming the first boron capsule. After one week of boron supplementation (day 7), there was a significant increase in free testosterone and a decrease in estradiol and TNF-α (Naghii et al. 2011).

A study conducted in post-menopausal women observed changes in sex hormone levels following administration of sodium borate capsules (Nielsen et al. 1987). 11 post-menopausal women (age 48 to 82 years) consumed a basal diet that supplied an average of 0.25 mg B/day for 119 days (23-day equilibration period, plus 4 × 24-day dietary periods). Women were kept in a metabolic unit under close supervision, and blood was drawn on days 16 and 24 for each 24-day dietary period. On day 120, women were given sodium borate at 3 mg boron/day in addition to the basal diet (total of 3.23 mg B/day or approximately 0.05 mg/kg bw/day) for 48 days (2 × 24-day dietary periods). A statistically significant increase in 17β-estradiol and testosterone was observed following boron supplementation (Nielsen et al. 1987). In addition, boron supplementation caused a decrease in the width of the QRS complex and an increase in blood pressure (Hunt et al. 1997).

Another boron supplementation study was conducted on 43 peri-menopausal women experiencing negative symptoms associated with menopause (that is, night sweats and hot flashes) (Nielsen and Penland 1999). The study was a double-blind crossover design in which women were given sodium borate at 2.5 mg/boron for 60 days before or after receiving a placebo containing lactose powder for 90 days. Blood was collected weekly throughout the study. A significant number of women reported increased frequency and severity of hot flashes and night sweats following ingestion of boron. Increased numbers of circulating white blood cells and 17β-estradiol concentrations were also noted in this study (Nielsen and Penland 1999). This assessment considers that the endocrine modulation and cardiac effects of boron supplementation observed in

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[7] Sex and gender-based terms used when describing human data are the same terms reported by study authors.

females are of concern and have not been adequately investigated in animal experiments.

A mother-child cohort study in Argentina evaluated the association between boron exposure from drinking water during pregnancy and birth size and weight (Igra et al. 2016). Concentrations of boron in drinking water ranged from 377 to 10 929 µg/L. Internal dose was measured in the serum, whole blood, and urine of pregnant women (n=180). The study found a statistically significant association between increased boron concentrations in whole blood, urine, and drinking water and decreased infant birth weight and length (Igra et al. 2016). A follow-up on the infants of the same pregnant women from Argentina assessed the impact of pre- and postnatal boron exposures on infant growth (n=120) (Hjelm et al. 2019). There was a strong inverse correlation between urinary boron concentrations in infants and both body weight and head circumference at 0 to 3 months, as well as length and head circumference at 3 to 6 months old (Hjelm et al. 2019). Conversely, a cross-sectional study of 30 pregnant women in Turkey observed no significant association between maternal boron concentrations in maternal or umbilical blood and birth weight (Caglar et al. 2014). In addition, a cohort study in Turkey found no association between boron exposure and adverse birth outcomes (that is, spontaneous abortion, miscarriage, infant and neonatal death, preterm birth, congenital abnormalities, sex ratio, and birth weight) (n=199) (Duydu et al. 2018a). These epidemiology studies all have notable limitations, including small sample sizes, failure to account for the potential confounding effects of co-exposure to other drinking water contaminants, and, in Caglar et al. (2014), exclusion of infants with congenital abnormalities (Health Canada 2023a).

A survey by Whorton et al. (1994) investigated reproductive outcomes in male boron workers from California (n=542). The calculated standardized birth ratio showed no adverse effects on fertility. There was a slight increase in female offspring numbers in boron workers compared with the national standard, but it was not statistically significant. This study is limited by the lack of quantitative exposure data and the absence of a comparable control group (ATSDR 2010; Health Canada 2012). In addition, using a standardized birth ratio is less sensitive than directly measuring testicular effects (US EPA 2004; Health Canada 2012).

A survey conducted in 2 Turkish villages compared the fertility rates of families exposed to boron via drinking water at 2 to 29 mg/L (high exposure group) and 0.03 to 0.4 mg/L (low exposure group) (Sayli et al. 1998). There was no significant difference in primary infertility rates reported between the 2 groups. There was a slight decrease in the male:female birth ratio, but it was not statistically significant (Sayli et al. 1998).
A follow-up survey on the same subpopulation found no association between boron exposure and rates of spontaneous abortion, stillbirth, and infant death (Tüccar et al.1998). Limitations of these studies include the reliance on survey data without clinical observations (ATSDR 2010).

In contrast, a similar survey conducted in China revealed that the prevalence of spontaneous abortion and delayed pregnancy among the wives of boron workers (n=809) was higher than that of local control groups (n=228) (Liu et al. 2005). However, this study did not include any quantitative measures of exposure.

Epidemiological studies have been conducted on workers in boron industries within China (for example, Chang et al. 2006; Robbins et al. 2008, 2010). In a study by Chang et al. (2006), no significant differences were observed between wives of boron workers compared with controls for delayed pregnancy, multiple births, miscarriages, induced abortions, stillbirths, and male to female offspring ratio. The sperm quality and reproductive history of a cohort in the same area in China were later re-investigated by Robbins et al. (2008, 2010). These studies investigated Y:X sperm ratios and sperm parameters (including total sperm count, sperm concentration, motility, morphology, DNA breakage, apoptosis, and aneuploidy) in 3 groups: boron workers (n=63), a community with high environmental boron exposure (n=39), and a control group with low environmental boron exposure (n=44) (Robbins et al. 2008, 2010). Higher concentrations of boron were observed in semen than in blood or urine, indicating that boron may accumulate in semen (ANSES 2012). After adjusting for age, there was a significant correlation between boron exposure, as determined by measured boron concentrations in urine and blood, and decreased Y:X sperm ratio (Robbins et al. 2008), but the correlation between boron exposure and other sperm parameters was insignificant (Robbins et al. 2010). Both studies are limited by their small sample size, which only allow for the detection of large differences in sperm parameters (ANSES 2012). The toxicological significance of the altered Y:X sperm ratio is unknown but could be indicative of an adverse effect on fertility (Health Canada 2023a). In contrast to the results of Robbins et al. (2008), Duydu et al. (2019) did not observe a statistically significant change in Y:X sperm ratio in occupationally exposed men from Turkey (n=304). However, the high variability noted in the control group limits the utility of this study.

A series of epidemiological studies assessed sperm parameters (sperm morphology, motility, and concentration) and reproductive hormone levels (follicle-stimulating hormone, luteinizing hormone, and total testosterone) in occupationally exposed male workers from Turkey (Duydu et al. 2011; Basaran et al. 2012) (n=204). No adverse effects on the reproductive toxicity indicators measured were observed. Consistent with Robbins et al. (2008, 2010), Duydu et al. (2011) observed a dose-dependent accumulation of boron in semen. A follow-up study (Duydu et al. 2018b) conducted in occupationally exposed Turkish men assessed the same fertility parameters (n=212). Similarly to previous studies, no boron-associated adverse effects were observed (Duydu et al. 2018b). However, it should be noted that these studies have limitations including small sample sizes and high boron blood concentrations across all exposure groups, resulting in the lack of a true low exposure group for comparison.

In contrast, Tarasenko et al. (1972) reported a low sperm count, reduced sperm motility, and elevated fructose content of seminal fluid in the semen analysis of 6 Russian workers, out of a total of 28 workers exposed to 22 to 80 mg boron/m^3 from vapours and aerosols of boron salts for 10 or more years. Exposed male workers reported decreased sexual function compared with a control group of 10 unexposed workers, according to the results of a Sexual Function of Man questionnaire. However, this study is very limited due to its small sample size; sparse data reporting regarding smoking habits, diet, and other chemical exposures; and the lack of methodology information on semen analysis (US EPA 2004; ATSDR 2010).

The current evaluation has determined that the available epidemiology studies are not of sufficient quality to select PODs for risk assessment. The studies have limitations, including small sample sizes, limited consideration of confounders, lack of a clear POD needed for dose-response analysis, lack of individual exposure data, and inadequate disease ascertainment.

National and international considerations

The US Environmental Protection Agency (US EPA 2004) developed an oral reference dose (RfD) using benchmark dose (BMD) analysis of the combined data sets of 2 developmental toxicity studies in rats, described above (Heindel et al. 1992; Price et al. 1996). Using the results of these studies, the US EPA (2004) derived a benchmark dose and lower confidence limit $(BMDL)_{05}$ of 10.3 mg B/kg bw/day on the basis of a reduction in fetal body weight. Uncertainty factors (UFs) of 3.3 (toxicokinetic extrapolation from animals to humans), 3.16 (toxicodynamic extrapolation from animals to humans), 2.0 (variability in human toxicokinetics), and 3.16 (variability in human toxicodynamics) were applied (total UF = 66) to calculate an RfD of 0.2 mg/kg bw/day. ATSDR (2010) adopted the same $BMDL_{05}$ and UFs when deriving their intermediate oral minimum risk level of 0.2 mg/kg bw/day.

EFSA (2013) derived an acceptable daily intake (ADI) for boric acid and sodium tetraborate using the NOAEL for reduction in fetal body weight (9.6 mg B/kg bw/day) established by Price et al. (1996). UFs of 4 (toxicokinetic), 2.5 (toxicodynamic), 1.8 (intraspecies toxicokinetic), and 3.2 (intraspecies toxicodynamic) were applied (total UF = 60) to establish an ADI of 0.16 mg B/kg bw/day.

The US EPA (2015a) selected a NOAEL of 8.8 mg B/kg bw/day for the two-year dog studies on the basis of hematological effects and testicular atrophy observed in the 90-day dog study (Weir and Fisher 1972). This endpoint was considered to be protective of toxicity observed in other species (rats, mice, rabbits). It should be noted that this endpoint by the US EPA (2015a) was selected on the basis of an analysis of the publication and not the original study data. The US EPA (2015a) applied UFs of 10 (interspecies variation) and 10 (intraspecies variation) (total UF = 100).

Health Canada's PMRA (Health Canada 2012) combined the results of the 90-day boric acid and borax studies in dogs (Weir and Fisher 1972) to calculate a BMDL of 2.9 mg B/kg bw/day on the basis of decreased testicular weight (Health Canada 2012, 2016). A target margin of exposure (MOE) of 300 was selected for their assessment (10x interspecies extrapolation, 10x intraspecies variation, 3x data set uncertainty). The additional threefold UF for data set deficiencies was applied because it is likely that histological changes in the testes will occur at a dose below those at which changes in testicular weight were noted (Health Canada 2012, 2016). Health Canada’s Water and Air Quality Bureau selected the same POD and MOE to derive a tolerated daily intake (0.01 mg B/kg bw/day) and health-based value (0.1 mg/L) for boron in drinking water (Health Canada 2023a).

8.1.3.1 Endpoint selection for systemic health effects

Consistent with previous assessments of boron (ATSDR 2010; ANSES 2012; ECHA 2014; Health Canada 2016, 2023a), it was determined that the available epidemiological data are insufficiently robust to confirm the absence of reproductive or developmental effects in humans. Overall, study limitations preclude the use of this data in deriving a POD for risk assessment.

Based on the weight of evidence, the BMDL of 2.9 mg B/kg bw/day was selected as a POD for the risk characterization of frequent or daily exposure scenarios and is based on decreases in testicular weight in dogs (Weir and Fisher 1972; Health Canada 2012, 2023a). This effect in response to boron exposure is consistent across animal species, although the sensitivity of the response varies between species (Health Canada 2016). Dogs are considered more sensitive to the testicular effects of boron than rats and mice; they therefore provide a conservative toxicological POD for predicting the potential risks in humans (Health Canada 2016). More recent animal studies assessing the effects of boron on fertility in males (Aktas et al. 2020; Wang et al. 2021) are limited to less sensitive species (that is, rats and mice). The POD selected (2.9 mg B/kg bw/day) is considered protective of the reduced pup weight observed in rat developmental toxicity studies (Heindel et al. 1992; Price et al. 1996; Watson et al. 2020). A target MOE of 300 was adopted from the Health Canada PMRA assessment of boron (10x interspecies extrapolation, 10x intraspecies variation, 3x data set uncertainty) (Health Canada 2012). The UF of 3 for data set uncertainty is applied to protect against the histological effects that are predicted to occur at doses lower than those at which changes in testicular weight were observed (Health Canada 2012).

The developmental NOAEL of 9.6 mg B/kg bw/day was selected in this assessment as a POD for the risk characterization of acute (infrequent/intermittent) exposure scenarios and is based on skeletal abnormalities (short rib XIII and wavy rib) (Price et al. 1996). The same developmental toxicity study was used by the US EPA (2004), ATSDR (2010) and EFSA (2013) in their assessments of boron. These assessments selected a reduction in fetal body weight as their critical effect for chronic (frequent or daily) exposure to boron. Intermittent or infrequent exposure to boron during pregnancy can impact skeletal development of the fetus (Narotsky et al. 1998); therefore, skeletal abnormalities were chosen as a critical effect for intermittent or infrequent exposure in this assessment. A total MOE of 300 (10x interspecies extrapolation, 10x intraspecies variation, 3x fetal sensitivity) was considered appropriate for this POD. The UF of 3 was applied in this assessment to protect against increased sensitivity of the young since toxicity to the fetus is observed at non-maternally toxic doses across multiple species, (that is, rats and rabbits) and the severity of those fetal effects (Heindel et al. 1992, 1994; Price et al. 1996).

8.1.4 Health effects from the inhalation route of exposure

Section 8.1.3 describes relevant literature on the systemic health effects of boric acid, its salts and its precursors from all routes of exposure. Only one study that addressed systemic effects via inhalation was identified (Tarasenko et al. 1972); however, it is of inadequate quality to be used for risk characterization. Therefore, the PODs from oral studies (Weir and Fisher 1972; Price et al. 1996) are used to characterize the risk of systemic exposure via inhalation, assuming an inhalation absorption rate of 100%.

PODs for systemic health effects do not consider potential portal-of-entry effects from inhalation exposure. Therefore, a literature search for inhalation portal-of-entry effects was conducted on boric acid, its salts and its precursors. It was determined on the basis of this search that adequate inhalation toxicity data for portal-of-entry effects were available for boric acid, sodium perborate (borax), boron oxide, boron trichloride, boron trifluoride, and diborane. Available exposure information for these 6 substances indicates that boric acid, sodium perborate, boron oxide, and boron trifluoride are present in products available to consumers (see section 4.2.3). Therefore, inhalation toxicity data specific to boron trichloride and diborane were not included in this assessment as they are not expected to result in inhalation exposure to the general population. Boric acid, sodium perborate, and boron oxide present similar portal-of-entry effects in the lung. As a result, the inhalation toxicity data for boric acid, sodium perborate, and boron oxide are considered together, while boron trifluoride is presented separately.

Boric acid, sodium perborate, and boron oxide

Animal studies

Wilding et al. (1959) assessed the inhalation toxicity of boron oxide aerosols in rats and dogs. 3 dogs were exposed to 57 mg/m^3 boron oxide for 23 weeks. Albino rats were exposed to 77 mg/m^3 (n=70), 175 mg/m^3 (n=4), or 470 mg/m^3 (n=20) boron oxide for 24, 12, and 10 weeks, respectively (6 hours/day, 5 days/week). At 470 mg/m^3, the aerosol generated a dense cloud of fine particles that covered the animals in dust. In rats, histopathological examination of lungs and trachea did not reveal any differences between exposed and control animals. Only mild respiratory irritation (reddish nasal exudate) was observed in some rats exposed to 470 mg/m^3.

Human studies

A series of cross-sectional surveillance studies by Garabrant et al. (1984, 1985) investigated the respiratory effects of boron oxide, boric acid, and borax dusts in US workers from the borax mining and refining industry. Workers exposed to borax dust for 5 or more years (n=629) were categorized into 4 groups according to exposure concentration: 1.1, 4.0, 8.4, and 14.6 mg borax/m^3 (Garabrant et al. 1985). A statistically significant, dose-related increase in respiratory symptoms was observed across exposure groups, including dryness of the mouth, nose, or throat, eye irritation, dry cough, nose bleeds, sore throat, productive cough, shortness of breath, and chest tightness. Pulmonary function tests and chest radiographs were not affected by borax exposure (Garabrant et al. 1985). Additionally, respiratory symptoms reported by a subgroup of workers who performed jobs that result in boron oxide or boric acid exposure (n=113) were compared with those reported by workers who had never held positions in areas where there was boron oxide or boric acid exposure but who had been exposed to low levels of borax (n=214) (Garabrant et al. 1984). Boron oxide and boric acid exposure areas had a mean concentration of 4.1 mg/m^3 total particulate, with a range of 1.2 to 8.5 mg/m^3. There was a significantly higher prevalence of eye irritation, dryness of mouth, nose, or throat, sore throat, and productive cough in the boron oxide and boric acid exposure group than in the control group (Garabrant et al. 1984).

Wegman et al. (1994) conducted a longitudinal study assessing pulmonary function in workers chronically exposed to borax dust. Available participants from Garabrant et al. (1985) were re-tested for pulmonary function 7 years after the original study (n=371). Cumulative exposure estimates for each participant were calculated using a time-weighted sum of the exposure for each job held by the participant during the seven-year period. Pulmonary function (forced expiratory volume in 1 second [FEV_1] and forced vital capacity [FVC]) declined over time; however, the loss in pulmonary function was not correlated with cumulative exposure estimates. The study authors noted that the annual loss for FEV_1 and FVC within the study population was close to the rate of loss seen in standard population studies. Additionally, the years worked between 1981 and 1988 were not associated with changes in FEV_1 and FVC, after adjusting for cigarette smoking. Acute studies exhibited a statistically significant, dose-related increase in respiratory symptoms (eye, nasal, and throat irritation, cough, breathlessness) with borate exposure (6-hour or 15-minute time-weighted average [TWA]). Daily exposure ranged from less than 1 mg/m^3 to greater than 15 mg/m^3. Borate type (decahydrate, pentahydrate, or anhydrous) had no significant impact on response rate (Wegman et al. 1994).

Male volunteers (n=11) were acutely exposed to sodium borate dusts (5, 10, 20, 30, 40 mg/m^3 sodium borate) during exercise for 10 minutes (Cain et al. 2004). Measures of nasal resistance and nasal secretions were taken before and after the exposure period. Subjects were asked to report the levels of feel or irritation of the nose, throat, and eyes during exposure. Exposure to 10 mg/m^3 caused a significant increase in nasal secretions (by mass). Subjects reported nasal irritation at 30 mg/m^3 and higher. Nasal resistance after exercise was consistent with the control at all doses tested. In a similar study, male and female volunteers were exposed to sodium borate (10 mg/m^3) or boric acid (2.5, 5.0, 10 mg/m^3 boric acid) for 47 minutes while exercising. Boric acid was considered non-irritating by the study subjects. An increase in nasal secretions was reported at 10 mg/m^3 boric acid; however, no dose-related changes in nasal airway resistance or breathing patterns were observed at all doses tested (Cain et al. 2008).

Boron trifluoride

Boron trifluoride monoetherate is anticipated to have the same portal-of-entry inhalation effects as boron trifluoride. Both boron trifluoride and boron trifluoride monoetherate are found in adhesive and sealant products (see section 4.2.3). It is expected that use of these products will result in inhalation exposure to boron trifluoride or boron trifluoride monoetherate due to the high volatility of these substances. Information regarding the concentration of these substances in products available to consumers was limited to boron trifluoride monoetherate in nail and eyelash adhesives, which have an infrequent or intermittent use pattern. Therefore, only acute inhalation exposure studies for boron trifluoride are considered in this assessment.

Rusch et al. (2008) assessed the acute inhalation toxicity of male and female rats (n=20) exposed to boron trifluoride mists (0, 8.53, 24.6, 74.7 mg/m^3 boron trifluoride) for 4 hours. Rats were necropsied 1 (n=10) or 14 days (n=10) after the exposure period. Ventral cartilage necrosis, anterior ventral hemorrhage (males only), and increased severity of ventral epithelial hyperplasia and ventral inflammatory cell infiltration were observed 1 day following exposure to 74.4 mg/m^3. Histopathological findings 14 days post-exposure were limited to ventral cartilage necrosis in 2 out of 10 animals (one male, one female) exposed to 74.4 mg/m^3.

8.1.4.1 Endpoint selection for health effects from the inhalation route of exposure

The inhalation data set on boron oxide, sodium perborate, and boric acid is limited. A repeated-dose inhalation toxicity study in dogs and rats exposed to boron oxide indicated no adverse portal-of-entry effects up to 57 and 470 mg/m^3, respectively (Wilding et al. 1959). Rats showed evidence of mild respiratory irritation at 470 mg/m^3 based on the presence of nasal discharge; however, this is not considered adverse (US EPA 2015a). Epidemiological studies on workers from the borax mining and refining industry exposed up to 14.6 mg/m^3 (Garabrant et al. 1984, 1985; Wegman et al. 1994) reported acute irritant effects, with no evidence of an effect on pulmonary function (US EPA 2004). These irritant effects are consistent with the results reported in other acute human inhalation studies, which exposed volunteers up to 40 mg/m^3 of sodium borate dust (Cain et al. 2004, 2008). The US EPA (2015a) considered the highest exposure concentration of 470 mg/m^3 from Wilding et al. (1959) to be a NOAEC given the absence of adverse effects in the lung. This dose is equivalent to 32 mg boron/kg bw/day, assuming a rat body weight of 0.35 kg, which is above the POD for chronic systemic effects (that is, 2.9 mg B/kg bw/day). Due to the lack of adverse portal-of-entry effects observed in animal and human studies, it is expected that the chronic systemic POD for boron will be protective of chronic inhalation exposure to boron oxide, sodium perborate, and boric acid.

Acute exposure to boron trifluoride caused ventral cartilage necrosis in rats exposed to 74.4 mg/m^3 for 4 hours, which persisted for up to 14 days post-exposure (Rusch et al. 2008). Inhalation of boron trifluoride monoetherate is anticipated to have the same inhalation toxicity as boron trifluoride; therefore, the results of Rusch et al. (2008) were used to characterize portal-of-entry effects for boron trifluoride monoetherate. A NOAEC of 24.6 mg/m^3 was selected as a POD for portal-of-entry effects due to intermittent or infrequent inhalation exposure to boron trifluoride monoetherate. A total MOE of 100 (10x interspecies extrapolation, 10x intraspecies variation) was considered appropriate for this POD.

8.1.5 Consideration of subpopulations who may have greater susceptibility

There are groups of individuals within the population who, due to greater susceptibility, may be more vulnerable to experiencing adverse health effects. The potential for susceptibility during different life stages or by sex has been considered from the available studies. In this assessment, developmental and reproductive toxicity studies were evaluated to assess the potential for susceptibility during these critical life stages and by sex. Males or people assigned male at birth are more susceptible at all ages to adverse health effects of boron than pregnant women and pregnant people, the developing fetus, and children. A reproductive effect based on decreased testicular weight was used as the critical health effect to characterize risk to the general population from chronic (frequent or daily) exposure to boron and is considered protective of developmental toxicity. With respect to infrequent or intermittent exposure to boron, the developing fetus was identified to be most susceptible to adverse health effects. A developmental effect based on skeletal abnormalities in the absence of maternal toxicity was used as the critical health effect to characterize risk from acute exposure to boron.

8.2 Exposure assessment

Measurements of boric acid, its salts and its precursors in environmental media, products, and humans are generally expressed in terms of total boron content corresponding to a fraction of the mass of boric acid on a molecular weight basis (that is, 17.5%). Exposure estimates are expressed as mass of boron per mass of body weight per day (for example, µg B/kg bw/day).

8.2.1 Biomonitoring

Biomonitoring data can provide a measure of integrated exposure of the population from all routes (for example, oral, dermal, and inhalation) and all sources (for example, environmental media, diet, and frequent or commonly used products to which they were exposed). High quality biomonitoring data for boron exist and are sufficient to adequately characterize exposure to the population in Canada, including subpopulations with the potential for greater susceptibility or greater exposure, such as males and other subpopulations, including children and pregnant women and pregnant people, who may be at an increased vulnerability of experiencing adverse health effects. With the availability of biomonitoring data that are representative of the population and adequate toxicokinetics data, exposure to boric acid was characterized using exposure estimates derived from the measurement of total boron in urine and blood.

Total boron concentrations were measured in urine as part of the CHMS cycle 5 (2016 to 2017) and cycle 6 (2018 to 2019) in participants aged 3 to 79 years living in Canada. The CHMS is a population-level survey designed by Statistics Canada to be representative of approximately 97%[8] of the population in Canada. Urinary boron was detected in over 98% of the population. The median and 95th percentile urine concentrations in the population aged 3 to 79 in cycle 6 (2018 to 2019) were 990 and 2,900 µg/g creatinine, respectively (Health Canada 2023d). These values were similar to or slightly higher than the urine boron concentrations measured in CHMS cycle 5 (2016 to 2017). In addition to the CHMS data, urinary boron concentrations have been measured in youth aged 3 to 19 years from 4 First Nations in Quebec as part of the First Nations Youth, Environment and Health (JES! –YEH!) pilot study. The median and 95th percentile urine concentrations were 991 and 4,387 µg/g creatinine, respectively (Lemire et al. 2019).

Total boron concentrations in blood have been measured in large studies conducted in Alberta and Northern Saskatchewan. As part of the Alberta biomonitoring program, blood samples from pregnant women were combined into 151 pooled samples for analysis, and blood samples from children were combined into 6 pooled samples for analysis (Alberta Health and Wellness 2008; Government of Alberta 2010). While this pooled study design can measure average concentrations from these samples, the ability to measure variability in the individual samples is lost. Blood concentrations measured in children aged 2 to 13 years (29 to 33 µg/L, 6 pooled samples) are similar to those found in pregnant women (13 to 34 µg/L, 151 pooled samples) (Alberta Health and Wellness 2008; Government of Alberta 2010). In a separate study conducted in Northern Saskatchewan, blood samples from 841 pregnant women were combined into 6 pooled samples for analysis. The study included participants from Cree and Dene communities in an area of Northern Saskatchewan where 87% of the population identified as Indigenous (67% First Nation, 20% Metis). The range of blood boron concentrations measured in the pooled samples in pregnant women from Alberta (13 to 34 µg/L, 151 pooled samples) was similar to that measured in Northern Saskatchewan (13 to 24 µg/L, 6 pooled samples) (Alberta Health and Wellness 2008; Government of Saskatchewan 2019). Owing to the pooled sample study design of the Alberta and Northern Saskatchewan studies, it is not possible to determine the upper tails of the exposure distribution in these populations (for example, 95th percentile or maximum concentrations based on the values of individual samples).

Outside of Canada, population-level studies (n≥50) conducted in the United Kingdom (UK), Germany, and France reported average blood boron concentrations ranging from 22 to 126 µg/L and upper percentile concentrations (95th percentile and maximum) ranging from 44 to 600 µg/L (Abou-Shakra et al. 1989; Goullé et al. 2005; Yazbeck et al.

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[8] The CHMS cycle 6 covers the population 3 to 79 years of age living in the 10 provinces. Excluded from the survey's coverage are: persons living in the 3 territories; persons living on reserves and other Indigenous settlements in the provinces; full-time members of the Canadian Forces; the institutionalized population; and residents of certain remote regions. Altogether, these exclusions represent approximately 3% of the target population.

2005; Heitland and Köster 2006). Goullé and colleagues (2005) measured 95th percentile blood boron concentrations of 44 µg/L in whole blood and 79 µg/L in plasma from 100 individuals in France. In another study conducted in northern France, the upper tails of the distribution of blood boron concentrations were 200 µg/L from individuals living in areas with <0.30 mg B/L in drinking water and 600 µg/L for individuals living in areas with >0.30 mg B/L in drinking water (Yazbeck et al. 2005). Maximum blood boron concentrations of 170.4 µg/L in whole blood and 48.1 µg/L in serum were measured from whole blood samples in the UK (Abou-Shakra et al. 1989). Heitland and Köster (2006) measured a maximum boron concentration of 195 µg/L in whole blood from a group of adults in northern Germany. Blood boron concentrations from the UK (Abou-Shakra et al. 1989), Germany (Heitland and Köster 2006), and France (Goullé et al. 2005) were similar. Blood boron concentrations reported in the study by Yazbeck and colleagues (2005) in northern France were higher than those from other studies conducted in Europe. This study was conducted in areas with boron concentrations in drinking water of up to and exceeding 0.3 mg/L, similar to boron concentrations measured in Canadian drinking water (Health Canada 2023a).

The boron biomonitoring data set includes data from across different life stages, ages, and sex. In a small study conducted in the US, pregnant and non-pregnant women had similar blood boron concentrations (Pahl et al. 2001). 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 human milk (transfer was greater via the placenta) (Harari et al. 2012). Boron urinary concentrations (in µg/g creatinine) in the CHMS data set exhibited a “U”-shaped age-related pattern across the population. The highest urinary concentration was measured in 3- to 5-year-olds, followed by a decline in concentrations until ages 12 to 19, after which urinary concentrations increased (Health Canada 2023d). Children aged 3 to 5 years (n=10) from 4 First Nations communities in Quebec also demonstrated higher median and 95th percentile urinary boron concentrations adjusted for creatinine in comparison with youth aged 6 to 19 years (n=19 to 21) in those same communities (Lemire et al. 2019). In the Alberta biomonitoring program, children aged 2 to 13 years had significantly higher blood boron concentrations than pregnant women (Government of Alberta 2010). Among adults, blood boron concentrations continue to increase with age (Usuda et al. 1997; Alberta Health and Wellness 2008; Hasbahceci et al. 2013). Generally, females have higher urinary boron concentrations than males, while conversely, males tend to have higher blood boron concentrations than females (Usuda et al. 1997; Health Canada 2021, 2023d).

An analysis was conducted to identify socio-demographic, behavioural, and physical factors associated with urinary boron concentrations collected in the CHMS (Malowany et al. 2023). The analysis combined data from participants aged 3 to 79 years from CHMS cycles 5 and 6, and the associations were examined by univariate and multivariate linear regression modelling. The natural log of urinary boron was fitted to the various factors; in addition, the natural log of urinary creatinine concentration was always included as a covariate in all models to adjust for urinary dilution. The urinary creatinine concentration was always highly significant in all models. Factors with p-values of less than 0.05 on the basis of univariate models were prioritized for the multivariate analysis. In the multivariate analyses, a stepwise variable selection procedure based on p-values was used to fit linear regression models to urinary boron concentrations. Separate models were fit for youth (3 to 19 years of age) and adults (20 to 79 years of age).

For the univariate analysis, no statistically significant relationship was observed between urinary boron concentrations and allostatic load index, pregnancy status, menopause, osteoporosis, country of birth, immigration status, language spoken at home, or neighbourhood factors such as housing type, walkability, parks, and crime rate. Allostatic load index is a summary measure of 9 health-based risk factors.

Urinary boron concentrations in youth were associated with age group and fruit and vegetable consumption (strongly significant), race and body mass index (BMI) class (moderately significant), and general health and household education (weakly significant). There was a negative association between boron concentrations and age, with the youngest age group (3 to 5) showing significantly higher boron concentrations than the age groups of 6 to 11 and 12 to 19 years. Youth identifying as White had significantly higher boron concentrations than those who identified as Asian or Black, but not those who identified as Indigenous or from other racial groups. Higher household education was associated with higher boron concentrations. Youth who were normal weight or underweight had significantly higher boron concentrations than those who were obese. Additionally, youth whose self-reported health was ranked as excellent had significantly higher boron concentrations than those whose health was good, fair, or poor. Higher fruit and vegetable consumption was associated with increased boron concentrations.

In adults, urinary boron concentrations were associated with sex, age, race, education, body mass index, smoking, and fruit and vegetable consumption. All covariates were strongly or moderately significant, except for race, which was only weakly significant. Females had significantly higher boron concentrations than males. Age was positively associated with urinary boron concentrations, which increased with age. This trend is opposite of what was observed in youth and would indicate a “U”-shaped age-related pattern in urinary boron concentrations across the general population. Adults identifying as White had significantly higher boron concentrations than those who identified as Black, but not those who identified as Asian, Indigenous, or from other racial groups. Higher education was positively associated with higher boron concentrations. Adults who were normal weight or underweight had significantly higher boron concentrations than those who were overweight or obese. Non-smokers had higher boron concentrations than smokers. Higher fruit and vegetable consumption was associated with increased boron concentrations.

In addition to the general population studies, targeted studies were available, which demonstrate an increase in blood boron concentrations following the use of supplements and mouthwash products containing boric acid or precursors to boric acid (Edwall et al. 1979; Green and Ferrando 1994; Hunt et al. 1997; Nielsen and Penland

1999; Wallace et al. 2002). For example, supplement use can result in significant increases in blood boron concentrations. Multiple studies conducted in peri- and post-menopausal women, and in weightlifters in Northern Ireland and the US examined blood boron concentrations before and after supplement use. Wallace et al. (2002) found that baseline blood concentrations averaging 14 µg/L peaked 4 hours after ingestion of an 11.6 mg boron dose at 136 µg/L and remained elevated 6 hours after dosing. 3 other studies found 1.5- to 1.7-fold increases in plasma boron concentrations following 2.5 and 3 mg doses from supplements (Green and Ferrando 1994; Hunt et al. 1997; Nielsen and Penland 1999). Blood boron increased fourfold 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 estimates (mg/kg bw/day) were derived using reverse dosimetry approaches. For urinary boron concentrations, a mass balance approach was used to produce estimates using the urinary excretion fraction (F_{UE}) for boron and creatinine excretion rates. For blood concentrations, a quantitative relationship between blood boron concentrations and boron intake estimates was used to estimate daily exposure (refer to Appendix H for details regarding the calculations). Exposure estimates were derived for the general population, susceptible subpopulations, and subpopulations with higher urinary boron concentrations.

Overall, exposure estimates derived using urine biomonitoring data from the CHMS are considered to be the best available total exposure data for the characterization of risk to the general population. There is higher confidence in the exposure estimates that are based on urine data, specifically for males and children, as opposed to those based on blood data as the urine data come from the large, highly robust CHMS data set, which has both central tendency and upper percentile data available to characterize exposure to people in Canada. While there is no significant difference in urinary boron measurements between females and males aged 3 to 5, males are more susceptible to adverse effects from boric acid. Data from the CHMS general population and males aged 3 to 5 will be carried forward to risk characterization. Further details on the biomonitoring concentrations and the reverse dosimetry models are presented in Appendices G and H, respectively.

Table 8-1. Predicted systemic daily exposure (µg/kg bw/day) to boric acid from urine biomonitoring data (µg/g creatinine)

Data set	Sex	Age	Median biomonitoring concentration (µg/g creatinine)	P95 biomonitoring concentration (µg/g creatinine)	Median exposure estimate (µg/kg bw/day)	P95 exposure estimate (µg/kg bw/day)
CHMS, cycle 6	M + F	3 to 79	990	2900	21.1	61.9
CHMS, cycle 6	M	3 to 79	950	2700	20.3	57.6

CHMS, cycle 6	M	3 to 5	2500	5500	44.9	98.9
CHMS, cycle 6	F	3 to 5	2600	6400	46.7	115.1

Abbreviations: M, male sex; F, female sex; P95, 95th percentile

8.2.2 Environmental media, food, and drinking water

Boron is a naturally occurring substance and is ubiquitous in environmental media; it is present in food, drinking water, air, soil, and dust. Total boron has been measured in airborne PM, soil, household dust, food, and drinking water.

Boron has been measured in both fine (PM_1, $PM_{2.5}$) and coarse (PM_{10}) particulate matter in targeted studies in Canada. Median concentrations of boron measured in the fine PM fraction of indoor and outdoor air collected in residential areas of Edmonton, Calgary, and Halifax were less than 5 ng/m^3 (n=262) (Health Canada 2013a, 2013b, 2013c). Median and 95th percentile concentrations of boron in coarse PM measured in Windsor, Ontario, in 2005 and 2006 were as follows: 5.38 and 13.6 ng/m^3 in personal air samples, 5.07 and 17.5 ng/m^3 in indoor air samples, and 12.4 and 27.9 ng/m^3 in outdoor air samples, respectively (Rasmussen et al. 2022). Boron was also measured in fine and course PM inside private cars, subways, and buses in Montreal, Ottawa, Toronto, and Vancouver. The median and 95th percentile $PM_{2.5}$ air concentrations of boron in cars, subways, and buses ranged from 0.99 to 21.95 ng/m^3 and from 1.24 to 39.06 ng/m^3, respectively. The highest average boron concentration was measured in Ottawa buses (22.39 ng/m^3) (personal communication, email from the Water and Air Quality Bureau, Health Canada, to the Existing Substances Risk Assessment Bureau, Health Canada, dated January 26, 2022; unreferenced). Assuming a daily 70-minute commute, bus commuters in Ottawa would be exposed to average boron concentrations in $PM_{2.5}$ of 6.21 µg/m^3, and the bus commute would account for 18% of the boron in air to which they were exposed.[9] Boron was not included as a target for outdoor air sampling ($PM_{2.5}$ or PM_{10}) conducted as part of the National Air Pollution Surveillance program.

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). There are over 200 minerals containing boron oxide, with the 4 most important boron-containing minerals being borax, kernite, colemanite, and ulexite (USGS 2018). Most boron compounds are transformed to borates in soil due to the presence of

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[9] Daily air concentration, transit influence was estimated using the highest average personal air sample from inside a bus of 22.39 ng/m^3 and the median ambient air concentration in $PM_{2.5}$ of 5.38 ng/m^3 (Rasmussen et al. 2022). Individuals are assumed to spend 70 minutes on transit per day (Van Ryswyk et al. 2017). Daily air concentration, transit influence = [(concentration of B in personal air, bus × (70 minutes) + (concentration of B in ambient air × (1370 minutes)]/1440 minutes

moisture; borates themselves are not further degraded in soil (ATSDR 2010). Anthropogenic sources of boron to soil include the application of boron-containing fertilizers and pest control products; 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). Reported total boron soil concentrations from residential, agricultural, and industrial areas in Canada, measured via hydrochloric/hydrofluoric digestion, range from 1 to 90 mg/kg (Penney 2004; Government of New Brunswick 2005; Jacques Whitford AXYS Ltd. 2008; Agriculture and Agri-Food Canada 2013; BC MOE 2017). The average boron soil concentration in the US is 33 mg/kg, ranging from less than 20 mg/kg to 300 mg/kg (USGS 1984). These data are discussed in more detail in section 7.3.1.

Nationally representative boron concentrations in household dust from Canadian homes were available from the Canadian House Dust Study (Rasmussen 2013). The amount of bioaccessible boron in these samples was measured via digestion in simulated stomach fluid, resulting in values that ranged from 7 to 2,091 mg/kg, with a median of 65.3 mg/kg (n=1025) (Rasmussen 2013). Sources of boron in household dust include the use of boric acid in building materials (for example, wood, cellulose insulation), products that contain boron substances (for example, cleaning products, pesticides), and tracked-in soil.

Dietary intake of boron from food is the greatest contributor to background exposure of people in Canada. Boron is a micro-essential nutrient for plant growth and enters the food chain through plants. The natural content of boron in 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). Most ingested boron is believed to convert to boric acid within the intestinal tract and is available for absorption (Hunt et al. 1997, 2004; Hunt 2006). Anthropogenic sources of boron into the food chain include the use of boron-containing fertilizers, food packaging (for example, adhesives, paper and paperboard), industrial point sources (for example, leaching), and agricultural runoff. Although boric acid is not approved for use on food/feed crops in Canada (Health Canada 2016), the import of foods treated with boron-containing pesticides from other countries is a potential source of dietary exposure, although the US EPA concluded that the use of boron in pesticides does not significantly add to naturally occurring boron levels in food/feed crops (US EPA 2015a).

Total boron is included in several monitoring programs for domestic and imported foods conducted by the Canadian Food Inspection Agency (CFIA), including the National Chemical Residue Monitoring Program (2008 to 2009 and 2009 to 2010), the Children's Food Project (2008 to 2009 and 2010 to 2011) and the Food Safety Action Plan (2009 to 2013) (CFIA [modified 2023b]). In over 30 000 samples available from 2008 to 2013, the highest average boron concentrations were measured in baking ingredients (25 µg/g), nut butters (16 µg/g), herbs and spices (14 µg/g), beverages (12 µg/g), seed butters (sunflower and tahini) (10 µg/g), and vegetable proteins (10 µg/g). Fruits and vegetables had average concentrations of 3 and 4 µg/g, while grains, dairy, and meat all had lower average concentrations of 1.5, 0.2, and 0.06 µg/g, respectively. Boron has also been measured in human milk and infant formulas. An average boron concentration of 30 µg/L was measured in human milk from 10 mothers in Newfoundland (Hunt et al. 2004), while concentrations of 120 µg/L were measured in 2 ready-to-serve infant formulas in the US (Hunt and Mecham 2001).

Concentrations of total boron from water treatment facilities and drinking water distribution systems in 2013 were available from Newfoundland and Labrador, New Brunswick, Quebec, Ontario, Manitoba, Saskatchewan, and the Yukon Territory. Mean concentrations for values above the reporting limit ranged from 0.01 to 0.38 mg/L, with values of up to 2.80 mg/L measured in distribution systems from the National Drinking Water Survey (Tugulea 2016; Health Canada 2023a). 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 well water are typically higher in regions composed of sedimentary rocks (CCME 2009). Elevated boron concentrations (>1 mg/L) may occur in groundwater from certain aquifers in Ontario, Manitoba, Saskatchewan, and Alberta (Health Canada 2023a). In most cases, boron concentrations in these sources are below 5 mg/L; however, concentrations as high as 8 to 9 mg/L have been reported (Lemay 2002; Desbarats 2009; Government of Manitoba 2010; Hamilton 2015; all as cited in Health Canada 2023a), which exceed Health Canada’s maximum acceptable concentration of 2 mg/L (Health Canada 2023a).

Probabilistic dietary intake estimates for the general population were derived by Health Canada’s Food Directorate in 2013. Dietary intakes incorporate the concentrations of total boron in food commodities collected from food monitoring programs (from 2008 to 2013) and from provincial drinking water data (2013). Consumption estimates were based on data from the Canadian Community Health Survey (CCHS), Cycle 2.2 on Nutrition (Statistics Canada 2004). Fruits (for example, apples), fruit juice, and vegetables (for example, carrots, tomatoes) were the primary contributors to dietary intake, accounting for 41% to 62% depending on the age group. Drinking water (tap and bottled) accounted for 3% to 16% of dietary intake. Although the concentration of boron was higher in some other foods (for example, baking ingredients, nut butters), the high consumption rates for fruits and vegetables resulted in these being the highest contributors to dietary exposure.

Estimates of average background exposure from environmental media, food, and drinking water were derived for the general population on the basis of concentrations of total boron measured in food, drinking water, air, soil, and house dust (Appendix D). Average background exposure ranges from 3.6 to 91.7 µg/kg bw/day. The primary contributor to background exposure is naturally occurring boron in food (that is, fruits, vegetables), followed by drinking water. Air, soil, and house dust are minor contributors to background exposure.

8.2.3 Products available to consumers

Boric acid is found in thousands of products available to people in Canada, including arts and crafts materials and toys, cleaning products, DIY products (including adhesives and sealants, automotive maintenance, home maintenance, paints and coatings), textiles and mattresses, self-care products (that is, cosmetics, natural health products, and non-prescription drugs), and swimming pools and spa maintenance products. Many of these products are used frequently, several times per week, or daily, resulting in chronic exposure, while others are used less frequently (less than one time per week) or intermittently (occasional use for up to one week of exposure), resulting in acute exposure.

Information on the types of products and the concentration of boric acid in products available to consumers was compiled from information submitted in response to surveys issued pursuant to section 71 of CEPA (Canada 2009, 2012); data gathering initiatives from the second phase of CMP (ToxEcology Environmental Consulting Ltd. 2012, 2014; Cheminfo Services Inc., 2013a, 2013b, 2013c; EHS 2013); voluntary stakeholder engagement activities and voluntary information submitted to Environment and Climate Change Canada and Health Canada during the data gathering and public comment stage; notifications submitted under the *Cosmetic Regulations* to Health Canada; the LNHPD [modified 2023]; the Health Canada internal Drug Product Database; publicly available databases and websites (for example, websites from producers, CPID c2017-2021); and material safety and technical datasheets (SDS Search Tool 2019).

To characterize exposure from products available to consumers, exposure estimates were derived using the ConsExpo Web model (ConsExpo Web 2020), the US EPA Residential Standard Operating Procedures (SOPs) (US EPA 2012b), unit exposure values from the Pesticide Handlers Exposure Database (PHED) (Health Canada 2002a; US EPA 2012b), US EPA SWIMODEL (US EPA 2003, 2016), and/or scenario-specific exposure algorithms. Exposure estimates were derived for different age groups and incorporate age-specific physiological parameters such as body weight, skin surface area, and inhalation rates (Health Canada [modified 2022b]). Exposure estimates from individual routes, such as dermal, oral, and inhalation, were summed to produce combined exposure estimates for a given product or scenario. Efforts were made to minimize the double counting of exposure between routes prior to combining exposures across routes. Exposure estimates are representative of a single event per day unless otherwise noted. Details on the derived exposure estimates, including inputs to the exposure models and algorithms, are presented in Appendices E and F.

A summary of the products assessed and the exposure estimates derived is presented below:

Arts and crafts materials and toys

Boric acid has been measured in arts and crafts materials. The US Art and Crafting Materials Institute measured the amount of bioaccessible boron in simulated stomach fluids (using ASTM standard D5517) in a variety of arts and crafts materials (Stopford 2013), the results of which are presented in Table 8-2. Many of these products, such as marker inks, ceramic glazes, pencils, and glue, are marketed to children or to teachers for use by children.

Table 8-2. Boron concentrations measured in arts and crafts materials

Arts and crafts materials	Boron (ppm) Gastric bioaccessible concentration
Marker inks	8.3 to 1,400
Technical drawing inks	1,400
Ceramic glazes	67 to 40,000
Pencils	27 to 650
Coloured sand	525
Paints and enamels including acrylic, gouache, watercolour, water colours, and oils	13 to 8,300
Colours and pigments including encaustic and acrylic	1,600 to 17,400
Glue	380 to 1,800

Abbreviation: ppm, parts per million

As it is regulated under the *Toys Regulations* (Canada 2011), boric acid has been measured in commercially available toys in Canada as part of cyclical compliance conducted by Health Canada. Under the regulations,[10] boric acid must not be used in a toy if it could become accessible to a child or if it could be released from the product if it breaks. From 2002 to 2019, geometric mean boron concentrations of 140 ppm (800 ppm boric acid) with a range of less than 0.7 to 9,160 ppm (4 to 52,400 ppm boric acid) was measured in slimes, dough, modelling clay and putties, paint, glue, clay, and plasticine toys that are easily manipulated and mouldable (Health Canada 2002b, 2004, 2009a, 2009b, 2017b, 2018a, 2019). In addition, borax is a common ingredient in make-your-own crafts and toys, including crystal formations, slime, and play dough.

Exposure estimates were derived for children using arts and crafts materials and playing with homemade and commercial modelling clay and slime, homemade crystals, craft paints, oil paints, markers, glue, and coloured sand. Combined exposure estimates across oral and dermal routes for frequent or daily use products, including slime and modelling clay, craft paint, markers, craft glue, and coloured sand, ranged from 0.23 to 443.7 µg/kg bw/day. Combined exposure estimates across dermal and inhalation routes for products used intermittently or infrequently, including crystal making and use of oil paints, ranged from 0.57 to 117 µg/kg bw/day. Overall, exposure for a 1-year-old infant playing with homemade modelling clay and slime resulted in the highest exposure estimate.

Cleaning products

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[10] In June 2023, Health Canada published a notice of intent to amend the *Toys Regulations* with respect to boric acid and salts of boric acid (Health Canada [modified 2023b]).

Boric acid is an ingredient in a variety of cleaning products and is often used as an enzyme stabilizer and bleaching agent (DeLeo et al. 2021). A survey of cleaning products manufacturers in Canada found approximately 200 cleaning products containing boron ingredients that ranged in concentration from 0.0026% to 11.3% boron, while 82% of products had boron concentrations below 0.36% (DeLeo et al. 2021). According to that industry survey and a search of publicly available data and voluntary information submitted to Health Canada, boric acid precursors are found in air fresheners, abrasive powders, general purpose cleaners and disinfectants, carpet spot remover and floor cleaning products, machine and hand wash dish detergents, machine and hand wash laundry detergents and pre-wash spot remover, metal polishes and degreasers, and toilet cleaning products (SDS Search Tool 2019; DeLeo et al. 2021; DPD [modified 2023]). There are a variety of formulation types, including powders, solid tablets, pastes, putties, liquids, and packaging options including aerosol and trigger sprays, diluted ready-to-use liquids, or concentrated liquids that require dilution in water. Many products, such as general purpose cleaners, have a number of different possible uses. Application methods may vary depending on the formulation and the use pattern of a particular product.

Dermal and inhalation exposures to cleaning products may result from mixing, loading, applying, wiping, and rinsing; there is also potential for dermal and oral exposures following application, via the transfer of remaining residue from dishes, clothing, or floors to the body. To characterize exposure from the use of cleaning products, exposure estimates were derived using the ConsExpo Web model (ConsExpo Web 2020), the US EPA Residential SOPs (US EPA 2012b), PHED unit exposures (Health Canada 2002a), and in some cases, scenario-specific algorithms. When available, exposure estimates considered the directions for use for a given product, including the initial concentration, dilution rate, and method of application. Alternative algorithms were used in some cases to refine exposure estimates. Inhalation exposure estimates were derived for powdered products and for liquid sprays. Some cleaning products are anticipated to be used daily or frequently (greater than once per week), while others are used less frequently or intermittently. Combined exposure estimates across dermal, oral, and inhalation routes for frequently used products ranged from 0.0089 to 730 µg/kg bw/day, and for products used intermittently, they ranged from 13 to 150 µg/kg bw/day. Exposure estimates varied depending on the concentration of boron in the product, the use rate, formulation type, and method of application. The highest exposure estimates came from the use by adults of powdered cleaning products as a general purpose cleaner or abrasive powder, on carpets and floors and in handwashing laundry. See Appendices E and F for further details.

DIY products

Boric acid is found in various DIY products including adhesives and sealants, automotive maintenance, home maintenance, and paints and coatings. Boron concentrations range from 0.11% to 18% in these products. There are a variety of product formulations (for example, putties, pastes, liquids, aerosols, or trigger sprays) and possible application methods that may result in consumer exposure through the dermal or inhalation route.

Dermal and inhalation exposure estimates were derived from the use of adhesives and sealants, automotive products, home maintenance, paints, and coatings from ConsExpo Web (2020) and unit exposure values (Health Canada 2002a, 2020b), which in select cases were refined using alternative algorithms. These types of products were expected to be used infrequently, less than once per week, or intermittently. Exposure estimates ranged from 0.12 to 61.9 µg/kg bw/day. The highest exposure estimates came from the application of rust paint with an airless sprayer.

Boron fluoride monoetherate and boron trifluoride are highly volatile substances and were both found in consumer adhesives. However, estimates of inhalation exposure to these substances from the use of adhesives could not be modelled as no concentration data were available.

Flame retardant uses

Several boric acid substances are used as flame retardants in carpet backing, cellulose insulation, batting and textiles used in furniture, building materials, futons and mattresses, floor tiles, nylon, paper and paperboard, plastics and rubber, silicones, textiles (flame retardant clothing, sleepwear), wall coverings, wood products, and wires and cables. In product testing conducted by Health Canada from 2012 to 2015 on children’s sleepwear, boron was detected in 9 of 23 samples, ranging from 0.2 to 2.2 ppm (personal communication, email from the Consumer and Hazardous Products Safety Directorate, Health Canada, to the Existing Substances Risk Assessment Bureau, Health Canada, dated July 24, 2017; unreferenced).

Extraction studies measuring the migration of boric acid from different fabrics and from mini- and full-scale twin mattresses have been conducted by the US Consumer Product Safety Commission (US CPSC 2005, 2006). In one study, a twin mattress with a boric acid-treated barrier was subject to a surface migration test. The mattress was covered with ticking fabric and a sheet, before being wet with simulated perspiration or simulated urine. 2 dry filter papers were placed on top of the wetted area and weighted down with a 1 pound per square inch (psi) weight for 6 hours. A mean migration rate of 6.7 µg boron/cm^2 over 6 hours was reported (Table 12b, US CPSC 2006), which is equivalent to a migration rate of 1.12 µg boron/cm^2/hour. This migration rate was then used to calculate a dermal exposure. The highest exposure estimate of 117.1 µg/kg bw/day was derived for an infant sleeping on a mattress or futon.

The US CPSC (2005) also evaluated the migration of boric acid from cotton batting, coated foam, and coated poly cotton in order to assess potential consumer exposure to flame retardants from skin contact. In this study, a filter paper was placed directly on the fabric and was wet with simulated perspiration or simulated urine for approximately 6 to 8 hours. The filter papers were either unweighted or weighted with a 1 psi weight. This was repeated for a total of 4 times to derive a cumulative percent migration of boron that ranged from 0.29% for cotton batting, unweighted, wet with simulated urine to 69.3% for coated poly-cotton, weighted and wet with simulated urine (Table 4, US CPSC 2005). The type of fluid applied (simulated perspiration versus simulated urine) did not have an impact on migration rates; however, the use of a weight resulted in boron migrating to the weighted filter paper at a higher rate than with the unweighted filter papers. The average percent migration of boron, per filter paper (2.3% when unweighted and 15.8% when weighted) was calculated by combining the simulated perspiration and simulated urine data points for cotton batting and coated poly-cotton materials. These migration values were used to estimate oral exposure from mouthing and dermal exposure from children's sleepwear. The combined oral and dermal exposures for infants from sleepwear was 0.3 µg/kg bw/day, which is lower than exposure from sleeping on a mattress containing boric acid.

Self-care products: cosmetics, natural health products, and non-prescription drugs

Self-care products are products that are available for purchase without a prescription from a doctor and fall into 3 broad categories in Canada: cosmetics, natural health products, and non-prescription drugs. Boric acid[11] is present as an ingredient, medicinal or non-medicinal, in over 1600 self-care products. In addition, it is present as a non-medicinal ingredient in approximately 40 prescription ophthalmic and otic drugs.

There are restrictions on the use of boric acid in self-care products. When used as a pH adjuster in cosmetics, boric acid and its salts have a maximum permitted concentration of 0.1% as boric acid (0.02% boron). In other cosmetics, the maximum permitted concentration for boric acid and its salts is 5% as boric acid (0.87% boron), and those cosmetics must include a warning and cautionary statement to the effect of not to be used on broken or abraded skin and on children under 3 years of age (Health Canada [modified 2022a]). Non-prescription drugs containing boric acid or sodium borate as a medicinal ingredient should not be administered to a child under 3 years of age (Canada 1978). Such restrictions as outlined in the Cosmetic Ingredient Hotlist are also referred to as additional details on boric acid and its salts such as sodium borate, borax, and sodium perborate in the NHPID [modified 2023]. Boron is also associated with a maximum daily dose of 700 µg/day for adults in the Multi-Vitamin/Mineral Supplements and Workout Supplements monographs, as well as with a maximum daily dose of 3.36 mg/day for adults in the Multiple Ingredient Joint Health Products monograph (Health Canada 2022b, 2022c, 2023c).

Boric acid is present in bath products, hair care and colour products, lotions and moisturizers, makeup, massage oil, nail products, ophthalmic and otic products including contact lens solutions, oral care products, oral health supplements (for example, multi-vitamin/mineral supplements, workout supplements, and joint health products), skin care products, soaps and cleansers, sunscreens, topical creams and

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[11] Boron nitride and borosilicates are common ingredients in cosmetics but are not considered to be precursors to boric acid; therefore, they are not included in this assessment.

ointments. The most common types of self-care products containing boron are oral health supplements (for example, multi-vitamin/mineral supplements, workout supplements, and joint health products). These are followed, to a lesser extent, by ophthalmic products (for example, eye drops, eye wash, and contact lens solution), body wash, and body lotions.

To characterize the exposure of users of self-care products, exposure estimates were derived using ConsExpo Web (2020) or product- and route-specific exposure algorithms incorporating information on product amount used and boron concentration. Information on product type and concentration was obtained from notifications submitted under the *Cosmetic Regulations* to Health Canada; from the LNHPD [modified 2023]; from Health Canada's Natural and Non-prescription Health Products Directorate (personal communication, email from the Natural and Non-prescription Health Products Directorate, Health Canada, to the Existing Substances Risk Assessment Bureau, Health Canada, dated February 5, 2020; unreferenced), and from the internal Drug Product Database (DPD [modified 2023]). Some self-care products are used daily or frequently (greater than once per week), while others are used less frequently or intermittently. Chronic exposures for frequent or daily use products ranged from 0.037 to 135.1 µg/kg bw/day, while acute exposures for products used infrequently or intermittently ranged from 0.049 to 257 µg/kg bw/day. The use of oral health supplements, anti-hemorrhoid cream, and body lotion resulted in the highest exposure estimates.

In addition, there is potential for inhalation exposure to boron trifluoride monoetherate from the use of nail and eyelash adhesives as this substance is highly volatile. An air concentration of 0.0088 mg boron trifluoride monoetherate/m^3 was derived using ConsExpo Web (2020).

Swimming pool and spa maintenance products

Boric acid is used in swimming pool and spa maintenance products as a water softener and pH stabilizer and to improve water clarity. Using PHED data, inhalation exposure estimates were derived for homeowners applying products to their pools (Health Canada 2002a). Dermal and oral estimates from swimming were derived using algorithms from the US EPA SWIMODEL (US EPA 2003). Children aged 4 to 8 years had the highest combined oral and dermal exposure at 348.8 µg/kg bw/day. Oral intake of pool water accounts for the majority of exposure.

Summary

Exposure estimates for the different product categories are summarized in Table 8-3 below. These estimates provide an indication of potential sources of exposure to boric acid above background exposure from environmental media, food, and drinking water.

Table 8-3. Summary of exposure estimates from products and uses available to consumers

Scenario	Population	Frequency of use	Exposure (µg/kg bw/day)
Arts and crafts materials and toys: making crystals, oil paint	Children, teens	Infrequent/ intermittent	0.57 to 117.0
Arts and crafts materials and toys: playing with slime, modelling clay, craft paint, markers, craft glue, coloured sand	Infants, children	Frequent/ daily	0.23 to 443.7
Cleaning products: carpet spot remover, hand washing china, polish/degreaser	Adults	Infrequent/ intermittent	13.0 to 150.0
Cleaning products: air freshener, abrasive powders, general purpose cleaner, floor cleaner, dishwasher detergent, laundry pre-wash spot remover and detergent, toilet cleaners	All ages	Frequent/ daily	0.0089 to 730.0
DIY products: sealants, caulking, automotive repair, automotive polish, tire mounting paste, synthetic brake fluid, wood glue, nail hole filler, wood cleaner, paint	Adults	Infrequent/ intermittent	0.12 to 61.9
Flame retardants: mattresses or futon, children's sleepwear	All ages	Frequent/ daily	0.30 to 117.1
Self-care products: hair colour, anti-itch and rash cream, anti-hemorrhoid cream, massage oil, face mask, eyebrow tint, massage oil, eye drops, eye wash, ear drops	All ages	Infrequent/ intermittent	0.049 to 257.0
Self-care products: beard conditioner, hair gel, hairspray, body soap, baby wash, body lotion, foot lotion, hair removal after-care, facial exfoliant, face makeup remover, face lotion, eyeshadow, bath bomb, multi-vitamin/mineral supplements, joint health products, other oral supplements, tooth whitener, toothpaste, mouthwash, lip moisturizer, eye drops, contact lens solution	All ages	Frequent/ daily	0.037 to 135.1

Swimming pool and spa products: application of maintenance products	Adults	Infrequent/ intermittent	0.16 to 4.0
Swimming pool and spa products: swimming	All ages	Frequent/ daily	32.5 to 348.8

8.2.4 Consideration of subpopulations who may have greater exposure

There are groups of individuals within the population who, due to greater exposure, may be more vulnerable to experiencing adverse health effects. Exposure estimates are routinely assessed by age to take into consideration physical and behavioural differences during different stages of life. In this exposure assessment, biomonitoring data for the population were drawn from the CHMS, from studies conducted in Alberta and Northern Saskatchewan, and from smaller targeted studies to examine differences in exposure by sex, age, race, and Indigenous status as well as socio-demographic, behavioural, and physical factors (Pahl et al. 2001; Alberta Health and Wellness 2008; Government of Alberta 2010; Government of Saskatchewan 2019; Lemire et al. 2019; Health Canada 2021, 2023d; Malowany et al. 2023). In addition to the JES!-YEH! study targeting First Nation youth in Quebec (Lemire et al. 2019), the Northern Saskatchewan study was conducted in an area with a high Indigenous population (Government of Saskatchewan 2019), and the CHMS included some Indigenous people living off reserve (Health Canada 2023d). No differences in exposure were observed between Indigenous and non-Indigenous people living in Canada. Across all biomonitoring data, females generally have higher urinary boron concentrations than males, while males have higher blood concentrations. There is a U-shaped pattern of urinary boron concentrations across the general population, but overall, children have higher urinary boron concentrations than adults. There were no differences in exposure associated with pregnancy or menopause status. Higher urinary boron concentrations were associated with people who identified as White, had higher education levels, were normal weight or underweight, were non-smokers, or had higher fruit and vegetable consumption (Malowany et al. 2023). Lastly, exposure estimates from background sources (environmental media, food, drinking water) and from products available to consumers were derived for different age groups to take into account differences in physiology, life stage, and behaviours.

8.3 Characterization of risk to human health

Results from animal experiments demonstrate that boric acid adversely affects fertility, reproduction, and development. The lowest POD in the animal data set for systemic effects was a BMDL of 2.9 mg B/kg bw/day for decreased absolute testicular weight, derived from 2 90-day dog studies. This endpoint is considered protective of the reduced pup weight and skeletal abnormalities observed in developmental toxicity studies (Heindel et al. 1992; Price et al. 1996; Watson et al. 2020) and was used for risk characterization of chronic exposure scenarios. A MOE of 300 was adopted from the Health Canada PMRA assessment of boron (10x interspecies extrapolation, 10x intraspecies variation, 3x data set uncertainty) (Health Canada 2012, 2016). The UF of 3 for data set uncertainty was applied to protect for histological effects that are predicted to occur at doses below those at which changes in testicular weight were observed (Health Canada 2012, 2016).

The developmental NOAEL of 9.6 mg B/kg bw/day was selected as a POD for the risk characterization of acute scenarios for systemic exposure to boron and is based on skeletal abnormalities (short rib XIII and wavy rib) (Price et al. 1996). Intermittent exposure to boron during pregnancy can impact skeletal development of the fetus (Narotsky et al. 1998); therefore, skeletal abnormalities were chosen as a critical effect in this characterization of risk to human health. A total target MOE of 300 (10x interspecies extrapolation, 10x intraspecies variation, 3x fetal sensitivity) was considered appropriate for this POD. The UF of 3 was applied to protect against increased sensitivity of the young since toxicity to the fetus is observed at non-maternally toxic doses across multiple species (that is, rats and rabbits) and takes into account the severity of those fetal effects (Heindel et al. 1992, 1994; Price et al. 1996).

The potential for cumulative effects was considered in this assessment by examining cumulative exposures to the moiety of boric acid. Given the availability of biomonitoring data representative of the population, systemic exposure to boric acid was characterized using exposure estimates derived from the measurement of total boron in people in Canada. Overall, exposure estimates derived using biomonitoring data from the CHMS are the best available total exposure data for the characterization of risk to the general population. Total concentrations of boron in blood or urine provide a biologically relevant, integrated measure of boric acid exposures that may occur across multiple routes (for example, oral, dermal, and inhalation) and sources (for example, environmental media, diet, and frequent or daily use products). There is higher confidence in the exposure estimates that are based on urine data, specifically for males and children, as opposed to those based on blood data as the urine data come from the large, highly robust CHMS data set, which has both central tendency and upper percentile data available to characterize exposure to people in Canada. Overall, children aged 3 to 5 years have the highest measurements of urinary boron. While there is no significant difference in urinary boron concentrations between females and males aged 3 to 5, males are more susceptible to the adverse effects of boric acid.

Exposure estimates and MOEs for the general population and for males aged 3 to 5 years, predicted using the CHMS urine biomonitoring data, are presented in Table 8-4.

Table 8-4. Relevant exposure estimates and resulting MOEs for urinary biomonitoring data

Population, age	Biomonitoring data (urine)	Exposure (µg/kg bw/day)	Critical effect	Critical effect level (mg/kg bw/day)	MOE
People in Canada, 3 to 79	Median CHMS urine data	21.1	Decreased testicular weight	BMDL 2.90	137

People in Canada, 3 to 79	P95 CHMS urine data	61.9	Decreased testicular weight	BMDL 2.90	47
Males, 3 to 5	Median CHMS urine data	44.9	Decreased testicular weight	BMDL 2.90	65
Males, 3 to 5	P95 CHMS urine data	98.9	Decreased testicular weight	BMDL 2.90	29

Abbreviations: MOE, margin of exposure; CHMS, Canadian Health Measures Survey; BMDL, benchmark dose level; P95, 95th percentile

[a] MOE = BMDL 2.9 (mg/kg bw/day) / exposure (µg/kg bw/day) * conversion mg/µg. There may be differences in MOEs due to rounding. Target MOE is 300.

The MOEs between the critical health effect level, a BMDL of 2.9 mg/kg bw/day for decreased testicular weight, and the exposure estimates ranged from 29 to 137. These MOEs are potentially inadequate to address uncertainties in the health effects and exposure data used to characterize risk.

Although total boron concentrations in blood or urine provide a biologically relevant, integrated measure of exposures that may occur across multiple routes (for example, oral, dermal, and inhalation) and sources (for example, environmental media, diet, and frequent or daily use products), the biomonitoring data alone do not provide information on sources of exposure to boric acid. The identification of sources of exposure is required if risk management actions are warranted.

People in Canada have daily background exposure to naturally occurring and anthropogenic boric acid from environmental media, food, and drinking water. As boron is an essential micronutrient for plant growth, the exposure estimates indicate, as expected, that naturally occurring boron in fruits and vegetables, and to a lesser extent in drinking water, represent primary sources of background exposure. Considering the universally recognized health benefits of diets rich in fruits and vegetables, background dietary exposure from natural sources is not considered to be of concern for people in Canada.

Boric acid in certain products available to consumers are additional sources of exposure above background. Exposure estimates for specific products and uses were derived to help identify potential sources of exposure. Exposure to boric acid from arts and crafts materials and toys, cleaning products, DIY products, flame retardants, self-care products, and swimming pool and spa home maintenance products is highly variable. Some products or uses resulted in relatively low exposure when compared with background exposure, while other products or uses had relatively high exposures. All product categories included products or uses that resulted in exposures higher than background exposure.

MOEs were derived for products in order to support potential risk management options, if required. Products with acute exposures resulting from infrequent (less than once per week but reoccurring) or intermittent (occasional for up to one week of exposure) use were compared to the critical effect level for acute exposure of 9.6 mg/kg bw/day for developmental effects. Products with chronic exposures resulting from daily or frequent use (greater than once per week but reoccurring) were compared to the critical effect level for chronic exposure of 2.9 mg/kg bw/day for testicular effects. MOEs for some arts and crafts materials and toys, cleaning products, flame retardants, DIY products, self-care products, and swimming pool and spa maintenance products are considered potentially inadequate to address uncertainties in the health effects and exposure data used to characterize risk. Exposure estimates and MOEs for products available to consumers are presented in Table 8-5; refer to Appendices E and F for exposure estimates and MOEs for specific products.

Table 8-5. Relevant exposure estimates and resulting MOEs for products available to consumers

Scenario	Population	Frequency of use	Exposure (μg/kg bw/day)	Critical effect level (mg/kg bw/day) and effect	MOE[a]
Arts and crafts materials and toys	Children, teens	Infrequent/ intermittent	0.57 to 117.0	NOAEL 9.6 skeletal abnormalities	82 to 16,950
Arts and crafts materials and toys	Infants, children	Frequent/ daily	0.23 to 443.7	BMDL 2.90 decreased testicular weight	7 to 12,429
Cleaning products	All ages	Frequent/ daily	0.0089 to 730.0	BMDL 2.90 decreased testicular weight	4 to 324,402
Cleaning products	Adults	Infrequent/ intermittent	13.0 to 150.0	NOAEL 9.6 skeletal abnormalities	64 to 738
DIY products	Adults	Infrequent/ intermittent	0.12 to 61.9	NOAEL 9.6 skeletal abnormalities	155 to 78,320
Flame retardants	All ages	Frequent/ daily	0.30 to 117.1	BMDL 2.90 decreased testicular weight	25 to 9,777
Self-care products	All ages	Frequent/ daily	0.037 to 135.1	BMDL 2.90 decreased testicular weight	21 to 79,368
Self-care products	All ages	Infrequent/ intermittent	0.049 to 257.0	NOAEL 9.6 skeletal abnormalities	37 to 195,335
Swimming pool and spa products: maintenance	Adults	Infrequent/ intermittent	0.16 to 4.0	NOAEL 9.6 skeletal abnormalities	2,389 to 61,018

Swimming pool and spa products: swimming	All ages	Frequent/ daily	32.5 to 348.8	BMDL 2.90 decreased testicular weight	8 to 89

Abbreviations: MOE, margin of exposure; BMDL, benchmark dose level; NOAEL, no-observed-adverse-effect level
[a] MOE = BMDL 2.9 (mg/kg bw/day) / exposure (µg/kg bw/day) * conversion mg/µg. There may be differences in MOEs due to rounding. Target MOE is 300.

In addition to systemic effects resulting from exposure to boric acid, a critical health effect was identified following inhalation exposure to boron trifluoride. Boron trifluoride monoetherate is anticipated to have the same effects and has been identified in certain adhesives, including certain nail and eyelash adhesives. A 4-hour TWA air concentration of 0.0088 mg boron trifluoride monoetherate/m^3 was derived for users. The MOE between the critical effect level of 24.6 mg boron trifluoride/m^3 for ventral cartilage necrosis following 4 hours of exposure and the 4-hour TWA concentration of 0.0088 mg boron trifluoride monoetherate/m^3 was 2,811. This MOE is considered adequate to address uncertainties in the health effects and exposure data used to characterize risk.

8.4 Uncertainties in the evaluation of risk to human health

Endocrine effects, specifically with respect to sex hormones, and cardiac effects were noted in human supplement studies in females and males. The possible long-term health effects of endocrine modulation and cardiac effects from boron exposure has not been adequately characterized in animal studies. Studies in male rats have assessed endocrine effects but are limited to subchronic duration. Currently, no animal studies exist that investigate the health effects associated with endocrine modulation in females or the health effects associated with cardiac effects.

There are inherent limitations in the dog studies used to derive the systemic POD in this assessment. Since the dog toxicity studies with borax and boric acid were conducted prior to the establishment of Good Laboratory Practices, they were considered by various regulatory bodies and review panels to be inadequate; for example, only 5 dogs/sex/dose were used (although this meets current OECD guidelines), the same control was used for both studies (this is justifiable since the studies were conducted concurrently), the dogs were sacrificed at various times, and one control animal showed some form of testicular lesion. Although the dog studies are dated, a provisional NOAEL was established for males on the basis of consistent testicular effects observed in each study, which occurred at lower doses than what was reported in the 1972 Weir and Fisher paper. Effects on male reproduction in response to boron exposure is consistent across animal species, although the sensitivity of the response varies between species. Dogs are considered more sensitive to the testicular effects of boron than rats and mice, and therefore provide a conservative toxicological POD for predicting the potential risks in humans. With respect to the hazard data set, the endpoint of decreased testicular weight represents the most sensitive adverse health effect that is considered relevant to chronic boron exposure.

Mechanism of action studies in rats (Ku et al. 1993) have exhibited changes in testicular histopathology at doses below those causing a decrease in testicular weight. Currently, there are no studies in dogs that have adequately characterized these histopathological changes.

The urine samples collected in the CHMS were spot urine samples. For the purposes of this approach, it is assumed that spot urine samples are representative of steady-state exposure concentrations across the population. However, the urine concentrations are influenced by the timing of exposure, timing of sampling, and the excretion rate of boric acid. The half-life and frequency of oral exposure for the boron moiety were taken into account when considering the steady-state assumption. For large population samples, such as the CHMS, it is reasonable to assume that the population distribution appropriately captures the variability in biomarker concentrations, even for short half-life substances. However, the availability of population-level 24-hour urine sample data would allow this assumption to be validated. Urine concentrations at the upper tails of the exposure distribution (for example, the 95th percentile) are likely from a mixture of individuals with elevated steady-state exposure and individuals with recent short-term exposure. Peaks in exposure may result from recent product use or other recent exposure coinciding with the timing of sampling.

It is not possible to determine the key contributing sources of boron exposure from the biomonitoring data. As a result, exposure estimates were derived from the use of products available to people in Canada. There is some uncertainty associated with the intake estimates for users of arts and crafts materials and toys, DIY products, flame retardant uses, self-care products, and swimming pool and spa maintenance products owing to the lack of comprehensive data on boric acid-containing products available to people in Canada, the identity of the boric acid precursor and concentration in the product, migration rate of boric acid from products, and information on how products are used, including the frequency of use.

There is uncertainty regarding the dermal absorption value used in the health risk assessment as the available studies report a wide range of absorption values (from less than 1% to 41%) and have several limitations, including poor mass balance, only one route of elimination measured, and vehicle selection. In addition, dermal absorption values were required for a wide range of products with different boron-containing substances (for example, boric acid, borax, sodium borate, zinc borate) that have different formulations.

9. Conclusion

Considering all available lines of evidence presented in this updated draft assessment, there is risk of harm to 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.

Considering all of the information presented in this updated draft assessment, 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.

It is therefore 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.

It is also proposed that boric acid, its salts and its precursors meet the persistence criteria but not the bioaccumulation criteria as set out in the *Persistence and Bioaccumulation Regulations* of CEPA.

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Appendices

Appendix A. Non-exhaustive list of boron-containing substances that are precursors or non-precursors of boric acid

This assessment focuses on a common moiety of concern, boric acid. Boron-containing chemicals on the *Domestic Substances List* (DSL; and associated hydrated forms that do not appear on the DSL) and the Revised In commerce List (R-ICL) at the time of the drafting of the first screening assessment were evaluated for their potential to be salts or precursors of boric acid (Environment Canada and Health Canada 2014). A non-exhaustive list of substances that were determined to be salts or precursors of boric acid are listed in Table A-1, and a non-exhaustive list of substances found to be non-precursors are listed in Table A-2. In total, 126[12] CAS RNs were identified as salts or precursors of boric acid. This includes the 19 substances identified as priorities for assessment (14 substances were identified as priorities for further action during categorization and 5 substances prioritized through other mechanisms (ECCC, HC [modified 2017])). In addition, 6 of the substances are on the R-ICL, 15 are hydrates of substances on the DSL, and 3 are commercially important minerals. These additional substances (for example, 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 regulatory or administrative lists; or other substances in commerce in Canada that may be boric acid precursors) were identified as potential contributors to boric acid in the environment and are included in the table below and further discussed in Environment Canada and Health Canada (2014). Most of these additional substances of interest are captured within HS codes, for which import data were requested from the CBSA.

Table A-1. Non-exhaustive list of boric acid, its salts and its precursors

CAS RN	Chemical name	Common name	Chemical class	List
1303-86-2[b]	Boron oxide (B_2O_3)	Boron oxide	Boric acids	DSL
10043-35-3[a]	Boric acid (H_3BO_3)	Boric acid	Boric acids	DSL
11113-50-1[b]	Boric acid (crude natural)	Boric acid	Boric acids	DSL
13460-50-9	Boric acid (HBO_2)	Boric acid	Boric acids	DSL
13460-51-0	Metaboric acid	Boric acid	Boric acids	R-ICL

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[12] The grouping in the first draft screening assessment included 130 CAS RNs. 4 substances were removed from this group. This includes 3 substances (CAS RN 102-98-7, 6273-99-0, and 10192-46-8), which were removed from the R-ICL in 2022 as it was determined that they do not have commercial activity in Canada for use in products under the *Food and Drugs Act* (Health Canada [modified 2023a]). In addition, one substance from the *Non-domestic Substances List* (CAS RN 16903-52-9) was removed as this substance does not have commercial activity in Canada above the trigger quantities specified in the *New Substances Notification Regulations (Chemicals and Polymers)* (Health Canada [modified 2022c]). However, these 4 substances would still meet the definition of boron-containing substances that are precursors or salts of boric acid.

CAS RN	Chemical name	Common name	Chemical class	List
1303-96-4[a]	Borax ($B_4Na_2O_7.10H_2O$) (disodium tetraborate decahydrate)	Borax	Borates	DSL
1318-33-8	Colemanite ($CaH(BO_2)_3.2H_2O$)	Colemanite	Borates	NA[c]
1319-33-1	Ulexite ($CaNaH_{12}(BO_3)_5.2H_2O$)	Ulexite	Borates	NA[c]
1330-43-4[a]	Boron sodium oxide ($B_4Na_2O_7$)	Sodium tetraborate	Borates	DSL
1332-07-6[a]	Boric acid, zinc salt	Zinc borate	Borates	DSL
1332-77-0	Boron potassium oxide ($B_4K_2O_7$)	Potassium tetraborate	Borates	DSL
1333-73-9	Boric acid, sodium salt	N/A	Borates	DSL
7632-04-4[a]	Perboric acid ($HBO(O_2)$), sodium salt	Sodium perborate	Borates	DSL
7775-19-1	Boric acid (HBO_2), sodium salt	Sodium borate	Borates	DSL
10332-33-9[b]	Perboric acid ($HBO(O_2)$), sodium salt monohydrate	Sodium perborate monohydrate	Borates	DSL
10486-00-7	Perboric acid ($HBO(O_2)$), sodium salt tetrahydrate	Sodium perborate tetrahydrate	Borates	NA[d]
10555-76-7	Sodium metaborate tetrahydrate ($Na_2B_2O_4.8H_2O$)	Sodium metaborate tetrahydrate	Borates	NA[d]
11128-29-3	Boron potassium oxide (B_5KO_8)	Potassium pentaborate	Borates	DSL
11128-98-6	Boric acid, ammonium salt	Ammonium borate	Borates	R-ICL
11138-47-9[b]	Perboric acid, sodium salt	N/A	Borates	DSL
12007-60-2[a]	Boron lithium oxide ($B_4Li_2O_7$)	Lithium tetraborate	Borates	DSL
12007-89-5[a]	Ammonium boron oxide ($(NH_4)B_5O_8$)	Ammonium pentaborate	Borates	DSL
12008-41-2	Boron sodium oxide ($B_8Na_2O_{13}$)	Disodium octaborate	Borates	DSL
12045-78-2	Boron potassium oxide ($B_4K_2O_7$), tetrahydrate	Potassium tetraborate tetrahydrate	Borates	NA[d]

CAS RN	Chemical name	Common name	Chemical class	List
12045-88-4	Sodium tetraborate pentahydrate (borax pentahydrate)	Borax pentahydrate	Borates	NA[d]
12046-04-7	Borate(5-), bis[m-oxotetraoxodiborato (4-)]-, ammonium tetrahydrogen, dihydrate, (T-4)-	Ammonium pentaborate tetrahydrate	Borates	NA[d]
12179-04-3	Sodium tetraborate pentahydrate	Borax pentahydrate	Borates	NA[d]
12229-12-8	Ammonium pentaborate tetrahydrate	Ammonium pentaborate tetrahydrate	Borates	NA[d]
12229-13-9	Boron potassium oxide (B_5KO_8), tetrahydrate	Potassium pentaborate octahydrate	Borates	NA[d]
12267-73-1	Boron sodium oxide ($B_4Na_2O_7$), hydrate (1:?)	Tetraboron disodium heptaoxide	Borates	NA[d]
12271-95-3[a]	Boron silver oxide ($B_4Ag_2O_7$)	Disilver tetraborate	Borates	DSL
12280-01-2	Zinc triborate monohydrate	Zinc hexaborate (Firebrake)	Borates	NA[d]
12280-03-4	Boron sodium oxide ($B_8Na_2O_{13}$), tetrahydrate	Disodium octaborate tetrahydrate (DOT)	Borates	NA[d]
12291-65-5	Colemanite ($CaH(BO_2)_3.2H_2O$)	Colemanite	Borates	NA[c]
12447-61-9	Boron zinc oxide ($B_6Zn_2O_{11}$) hydrate (2:15)	Zinc borate	Borates	NA[d]
12767-90-7[a]	Boron zinc oxide ($B_6Zn_2O_{11}$)	Zinc borate	Borates	DSL
13453-69-5[a]	Boric acid (HBO_2), lithium salt	Lithium metaborate	Borates	DSL
13701-59-2	Boric acid (HBO_2), barium salt	Barium borate	Borates	DSL
13701-64-9	Boric acid (HBO_2), calcium salt	Calcium metaborate	Borates	DSL
13709-94-9	Boric acid (HBO_2), potassium salt	Potassium metaborate	Borates	DSL
13840-56-7[b]	Boric acid (H_3BO_3), sodium salt	Sodium orthoborate	Borates	DSL

CAS RN	Chemical name	Common name	Chemical class	List
16800-11-6	Sodium metaborate dihydrate ($Na_2B_2O_4.4H_2O$)	Sodium metaborate dihydrate	Borates	NA[d]
20786-60-1	Boric acid (H_3BO_3), potassium salt	Potassium orthoborate	Borates	DSL
22694-75-3	Boric acid (H_3BO_3), triammonium salt	Ammonium borate	Borates	R-ICL
27522-09-4	Boric acid (H_3BO_3), ammonium salt	Ammonium borate	Borates	R-ICL
68442-99-9	Manganese, borate neodecanoate complexes	Manganese boron neodeconoate	Borates	DSL
68457-13-6[a]	Cobalt, borate neodecanoate complexes	Cobalt boron neodeconoate	Borates	DSL
138265-88-0	Boron zinc hydroxide oxide ($B_{12}Zn_4(OH)_{14}O_{15}$)	Zinc borate (Firebrake)	Borates	NA[d]
149749-62-2	Zinc borate ($4ZnO.B_2O_3.H_2O$)	Zinc borate	Borates	NA[d]
102-24-9	Boroxin, trimethoxy-	Trimethoxyboroxine	Borate esters	DSL
121-43-7	Boric acid (H_3BO_3), trimethyl ester	Trimethyl borate	Borate esters	DSL
150-46-9	Boric acid (H_3BO_3), triethyl ester	Triethyl borate	Borate esters	DSL
2467-16-5	Boric acid (H_3BO_3), tricyclohexyl ester	Tricyclohexyl borate	Borate esters	DSL
2665-13-6	1,3,2-Dioxaborinane, 2,2'-[(1-methyl-1,3-propanediyl)bis(oxy)]bis[4-methyl-	Tributyleneglycol biborate	Borate esters	DSL
5743-34-0	D-Gluconic acid, cyclic 4,5-ester with boric acid (H_3BO_3), calcium salt (2:1)	Calcium borogluconate	Borate esters	DSL
7091-41-0	2,4,8,10-Tetraoxa-3,9-diboraspiro[5.5]undecane, 3,9-bis(4-methylphenyl)-	N/A	Borate esters	DSL
14697-50-8	1,3,2-Dioxaborinane, 2,2'-oxybis[4,4,6-trimethyl-	Hexyleneglycol biborate	Borate esters	DSL

CAS RN	**Chemical name**	**Common name**	**Chemical class**	**List**
51136-86-8	Hexanoic acid, 2-ethyl-, trianhydride with boric acid (H_3BO_3)	N/A	Borate esters	DSL
67859-60-3	Boroxin, tris[(2-ethylhexyl)oxy]-	Tri-2-ethylhexyl metaborate	Borate esters	DSL
68130-12-1	Boric acid, 2-aminoethyl ester	MEA-borate	Borate esters	R-ICL
68298-96-4	Ethanol, 2,2’-iminobis-, monoester with boric acid	DEA-borate	Borate esters	DSL
71889-05-9	Benzenemethanol, 4-amino-α-(4-amino-3,5-dimethylphenyl)-α-(2,6-dichlorophenyl)-3,5-dimethyl-, monoester with boric acid (H_3BO_3)	N/A	Borate esters	DSL
89325-22-4	9-Octadecenoic acid (Z)-, (2-hydroxy-1,3,2-dioxaborolan-4-yl)methyl ester	N/A	Borate esters	DSL
10377-81-8	Ethanol, 2-amino-, monoester with boric acid	MEA-borate	Borate esters (monoalkanolamine borate)	DSL
26038-87-9	Boric acid (H_3BO_3), compd. with 2-aminoethanol	MEA-borate	Borate esters (monoalkanolamine borate)	DSL
26038-90-4	Boric acid (H_3BO_3), compd. with 1-amino-2-propanol	MIPA-borate	Borate esters (monoalkanolamine borate)	DSL
68003-13-4	Boric acid (H_3BO_3), compd. with 1-amino-2-propanol (1:1)	MIPA-borate	Borate esters (monoalkanolamine borate)	R-ICL
68586-07-2	Boric acid (H_3BO_3), compd. with 2-aminoethanol (1:1)	Orthoboric acid ethanolamine salt	Borate esters (monoalkanolamine borate)	DSL

CAS RN	**Chemical name**	**Common name**	**Chemical class**	**List**
68797-44-4	Boric acid (H_3BO_3), compd. with 2-aminoethanol (1:3)	Boric acid, monoethanolamine salt	Borate esters (monoalkanolamine borate)	DSL
93964-50-2	Boric acid (H_3BO_3), compd. with 2-amino-2-methyl-1-propanol	N/A	Borate esters (monoalkanolamine borate)	DSL
64612-24-4	Boric acid (H_3BO_3), compd. with 2,2'-iminobis[ethanol] (1:1)	Orthoboric acid diethanolamine salt	Borate esters (dialkanolamine polyborate)	DSL
67952-33-4	Boric acid (H_3BO_3), compd. with 2,2'-iminobis[ethanol]	Orthoboric acid diethanolamine salt	Borate esters (dialkanolamine polyborate)	DSL
68425-66-1	Boric acid, compd. with 2,2'-iminobis[ethanol]	Diethanolamine borate	Borate esters (dialkanolamine polyborate)	DSL
68954-07-4	Boric acid, reaction products with diethanolamine	N/A	Borate esters (dialkanolamine polyborate)	DSL
10049-36-2	Boric acid (H_3BO_3), compd. with 2,2',2''-nitrilotris[ethanol]	Boric acid, triethanolamine salt	Borate esters (trialkanolamine borate)	DSL
10220-75-4	Boric acid (H_3BO_3), compd. with 2,2',2''-nitrilotris[ethanol] (1:1)	Boric acid, triethanolamine salt	Borate esters (trialkanolamine borate)	DSL

CAS RN	**Chemical name**	**Common name**	**Chemical class**	**List**
68512-53-8	Boric acid (H_3BO_3), reaction products with ethanolamine and triethanolamine	N/A	Borate esters (monoalkanolamine/trialkanolamine polyborate)	DSL
75-23-0	Boron, (ethanamine)trifluoro-, (T-4)-	Boron trifluoride ethylamine	Boron halides	DSL
109-63-7	Boron, trifluoro[1,1’-oxybis[ethane]]-, (T-4)-	Boron fluoride monoetherate	Boron halides	DSL
368-39-8	Oxonium, triethyl-, tetrafluoroborate(1-)	Triethoxonium fluoroborate	Boron halides	DSL
456-27-9	Benzenediazonium, 4-nitro-, tetrafluoroborate(1-)	4-Nitrobenzenediazonium tetrafluoroborate	Boron halides	DSL
592-39-2	Boron, trifluoro(piperidine)-, (T-4)-	Trifluoro(piperidine)boron	Boron halides	DSL
2145-24-6	Benzenediazonium, 4-sulfo-, tetrafluoroborate(1-)	N/A	Boron halides	DSL
7445-38-7	Boron, trifluoro[N-(phenylmethyl) benzenemethanamine]-, (T-4)-	Boron trifluoridedibenzylamine complex	Boron halides	DSL
7637-07-2	Borane, trifluoro-	Boron trifluoride	Boron halides	DSL
10294-33-4	Borane, tribromo-	Boron tribromide	Boron halides	DSL
10294-34-5	Borane, trichloro-	Boron trichloride	Boron halides	DSL
13755-29-8	Borate(1-), tetrafluoro-, sodium	Sodium fluoborate	Boron halides	DSL
13814-96-5[a]	Borate(1-), tetrafluoro-, lead(2++) (2:1)	Lead fluoroborate	Boron halides	DSL
13814-97-6	Borate(1-), tetrafluoro-, tin(2++) (2:1)	Tin fluoroborate	Boron halides	DSL

CAS RN	Chemical name	Common name	Chemical class	List
13826-83-0[a]	Borate(1-), tetrafluoro-, ammonium	Ammonium fluoroborate	Boron halides	DSL
14075-53-7	Borate(1-), tetrafluoro-, potassium	Potassium fluoroborate	Boron halides	DSL
14486-19-2[a]	Borate(1-), tetrafluoro-, cadmium (2:1)	Cadmium fluoborate	Boron halides	DSL
16872-11-0	Borate(1-), tetrafluoro-, hydrogen	Fluoroboric acid	Boron halides	DSL
34762-90-8	Boron, trichloro(N,N-dimethyl-1-octanamine)-, (T-4)-	N/A	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-)]	N/A	Boron halides	DSL
72140-65-9	Sulfonium, (2-cyano-1-methylethyl)dodecylethyl-, tetrafluoroborate(1-)	N/A	Boron halides	DSL
74-94-2	Boron, trihydro(N-methylmethanamine)-, (T-4)-	Dimethylamine borane	Boranes	DSL
7337-45-3	Boron, trihydro(2-methyl-2-propanamine)-, (T-4)-	tert-Butylamine borane	Boranes	DSL
12386-10-6	Methanaminium, N,N,N-trimethyl-, octahydrotriborate(1-)	Tetramethyl ammonium octahydrotriborate	Boranes	DSL
16940-66-2	Borate(1-), tetrahydro-, sodium	Sodium borohydride	Boranes	DSL
19287-45-7	Diborane	Diborane	Boranes	DSL
98-80-6	Boronic acid, phenyl-	Benzeneboronic acid	Organoboron compounds	DSL
143-66-8	Borate(1-), tetraphenyl, sodium	Sodium tetraphenylborate	Organoboron compounds	DSL
3262-89-3	Boroxin, triphenyl	Triphenyl boroxin	Organoboron compounds	DSL

CAS RN	Chemical name	Common name	Chemical class	List
13331-27-6	Boronic acid, (3-nitrophenyl)-	3-Nitrobenzeneboronic acid	Organoboron compounds	DSL
66472-86-4	Boronic acid, (3-aminophenyl)-, sulfate (2:1)	3-Aminophenylboric acid hemisulphate	Organoboron compounds	DSL
91782-44-4	1,2-Ethanediol, reaction products with boron sodium oxide ($B_4Na_2O_7$)	Boric acid ($H_2B_4O_7$), disodium salt, reaction products with ethylene glycol	Organics	DSL
39405-47-5	Dextrin, reaction products with boric acid	Borated dextrine	UVCBs	DSL
58450-10-5	D-gluco-Heptonic acid, (2ξ)-, ester with boric acid (H_3BO_3), sodium salt	N/A	UVCBs	DSL
68131-51-1	Caseins, borated	Borated casein	UVCBs	DSL
68411-21-2	Boric acid (HB_5O_8), sodium salt, reaction products with propylene glycol	N/A	UVCBs	DSL
68411-22-3	Phosphoric acid, reaction products with aluminum hydroxide and boric acid (H_3BO_3)	N/A	UVCBs	DSL
68511-18-2	Starch, borate	Starch borate	UVCBs	DSL
68610-78-6	Acetic acid, anhydride, reaction products with boron trifluoride and 1,5,9-trimethyl-1,5,9-cyclododecatriene	N/A	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	Longifolene formate	UVCBs	DSL

CAS RN	**Chemical name**	**Common name**	**Chemical class**	**List**
69898-30-2	Starch, base-hydrolyzed, borated	N/A	UVCBs	DSL
72066-70-7	Sulfite liquors and cooking liquors, spent, borated	N/A	UVCBs	DSL
90530-04-4	2-Propanol, reaction products with boron trifluoride and 5-ethylidenebicyclo[2.2.1]hept-2-ene	N/A	UVCBs	DSL
91770-03-5	Fatty acids, tall-oil, reaction products with boric acid (H_3BO_3) and diethanolamine	N/A	UVCBs	DSL
93924-91-5	Boric acid (H_3BO_3), reaction products with 2,2’-[(C16-18 and C16-18-unsaturated alkyl)imino]bis[ethanol]	N/A	UVCBs	DSL
121053-02-9	Sulfonic acids, petroleum, calcium salts, overbased, reaction products with acetic acid, boric acid and 12-hydroxyoctadecanoic acid	N/A	UVCBs	DSL
124751-09-3	Caseins, reaction products with ammonium hydroxide, boron sodium oxide ($B_4Na_2O_7$), sodium hydroxide and trisodium phosphate	N/A	UVCBs	DSL
125328-30-5	Starch, acid-hydrolyzed, borated	N/A	UVCBs	DSL
127087-85-8	Boric acid (H_3BO_3), reaction products with 2-(butylamino)ethanol and diethanolamine	N/A	UVCBs	DSL
129783-46-6	Borate(1-), tetrafluoro-, hydrogen, reaction products with 2-(ethylthio)ethanol	N/A	UVCBs	DSL

Abbreviations: N/A, not applicable; NA, not available; DSL, *Domestic Substances List*; R-ICL, *Revised In Commerce List*; UVCB, substance of unknown or variable composition, complex reaction products or biological materials

[a] Substance found to meet categorization criteria (ECCC, HC [modified 2017])

[b] This substance did not meet categorization criteria but was prioritized through other mechanisms (ECCC, HC [modified 2017]).

[c] Substance of commercial importance

[d] Hydrate of a substance on the DSL

Table A-2. Non-exhaustive list of substances considered non-precursors of boric acid

CAS RN	Chemical name	Chemical class	List
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
10043-11-5	Boron nitride (BN)	Borides	DSL
12008-21-8	Lanthanum boride (LaB_6), (OC-6-11)-	Borides	DSL
12045-63-5	Titanium boride (TiB_2)	Borides	DSL
12069-32-8	Boron carbide (B_4C)	Borides	DSL

Abbreviation: DSL, *Domestic Substances List*

Appendix B. Sediment ecotoxicological data

Table B-1. Available sediment toxicity data

Group	Species name (common name)	Endpoint and duration	Response	Effects concentration	Reference
Invertebrate	*Chironomus riparius* (freshwater midge)	28-d NOEC	Multiple[a]	37.8 mg B/kg	Gerke et al. 2011a[b]
Invertebrate	*Chironomus riparius*	28-d LOEC	Multiple[a]	>37.8 mg B/kg	Gerke et al. 2011a[b]
Invertebrate	*Chironomus riparius*	28-d NOEC	Survival, emergence	20.4 mg B/L	Gerke et al. 2011b[c]
Invertebrate	*Chironomus riparius*	28-d LOEC	Survival, emergence	43.3 mg B/L	Gerke et al. 2011b[c]
Invertebrate	*Chironomus riparius*	28-d EC_{10}	Survival	43 mg B/L	Gerke et al. 2011b[c]
Invertebrate	*Chironomus riparius*	28-d EC_{50}	Survival	46.5 mg B/L	Gerke et al. 2011b[c]
Invertebrate	*Chironomus riparius*	28-d EC_{10}	Emergence	40.8 mg B/L	Gerke et al. 2011b[c]

Group	Species name (common name)	Endpoint and duration	Response	Effects concentration	Reference
Invertebrate	*Chironomus riparius*	28-d EC_{50}	Emergence	50.2 mg B/L	Gerke et al. 2011b[c]
Invertebrate	*Chironomus riparius*	28-d NOEC	Multiple[d]	43.3 mg B/L	Gerke et al. 2011b[c]
Invertebrate	*Chironomus riparius*	28-d LOEC	Multiple[d]	>43.3 mg B/L	Gerke et al. 2011b[c]
Invertebrate	*Chironomus riparius*	28-d NOEC	Mortality, emergence	180 mg B/kg	Hooftman et al. 2000
Invertebrate	*Chironomus riparius*	28-d LOEC	Mortality, emergence	320 mg B/kg	Hooftman et al. 2000
Invertebrate	*Chironomus riparius*	28-d LC_{50}	Mortality	278 mg B/kg	Hooftman et al. 2000
Invertebrate	*Chironomus riparius*	28-d NOEC	Mortality, emergence	32 mg B/L	Hooftman et al. 2000
Invertebrate	*Chironomus riparius*	28-d LOEC	Mortality, emergence	59 mg B/L	Hooftman et al. 2000
Invertebrate	*Chironomus riparius*	28-d LC_{50}	Mortality	49 mg B/L	Hooftman et al. 2000
Invertebrate	*Lampsilis siliquoidea* (fatmucket clam)	21-d NOEC	Survival	254.9 mg B/kg	Hall et al. 2014
Invertebrate	*Lampsilis siliquoidea*	21-d IC_{25}	Survival	363.1 mg B/kg	Hall et al. 2014
Invertebrate	*Lampsilis siliquoidea*	21-d NOEC	Survival	31.6 mg B/L	Hall et al. 2014
Invertebrate	*Lampsilis siliquoidea*	21-d IC_{25}	Survival	45.0 mg B/L	Hall et al. 2014
Invertebrate	*Lampsilis siliquoidea*	21-d NOEC	Growth	80.6 mg B/kg	Hall et al. 2014
Invertebrate	*Lampsilis siliquoidea*	21-d IC_{25}	Growth	310.6 mg B/kg	Hall et al. 2014
Invertebrate	*Lampsilis siliquoidea*	21-d NOEC	Growth	10 mg B/L	Hall et al. 2014
Invertebrate	*Lampsilis siliquoidea*	21-d IC_{25}	Growth	38.5 mg B/L	Hall et al. 2014
Invertebrate	*Lumbriculus variegatus* (aquatic worm)	28-d NOEC	Survival	100.8 mg B/kg	Hall et al. 2014
Invertebrate	*Lumbriculus variegatus*	28-d NOEC	Survival	12.5 mg B/L	Hall et al. 2014

Group	Species name (common name)	Endpoint and duration	Response	Effects concentration	Reference
Invertebrate	*Lumbriculus variegatus*	28-d IC_{25}	Survival	12.7 mg B/L	Hall et al. 2014
Invertebrate	*Lumbriculus variegatus*	28-d NOEC	Growth	201.6 mg B/kg	Hall et al. 2014
Invertebrate	*Lumbriculus variegatus*	28-d IC_{25}	Growth	235.5 mg B/kg	Hall et al. 2014
Invertebrate	*Lumbriculus variegatus*	28-d NOEC	Growth	25 mg B/L	Hall et al. 2014
Invertebrate	*Lumbriculus variegatus*	28-d IC_{25}	Growth	25.9 mg B/L	Hall et al. 2014

Abbreviations: EC_x, the concentration of a substance that is estimated to cause some effect on x% of the test organisms; IC_x, the concentration of a substance that is estimated to cause some inhibition where the response on x% of the test organisms; LC_{50}, median lethal concentration; NOEC, no-observed-effect concentration; LOEC, lowest-observed-effect concentration

[a] Survival, emergence, emergence time (male, female, total), development rate (male, female, total)

[b] Test conducted using spiked sediments.

[c] Test conducted using spiked water.

[d] Emergence time (male, female, total), development rate (male, female, total)

Appendix C. Soil toxicity 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	*Folsomia candida* (springtail)	28 to 42-d EC_{10}	Reproduction	5.5	Amorim et al. 2012
Plant (monocot)	*Zea mays* (corn)	70-d EC_{10}	Growth (yield shoot)	7.2	Hosseini et al. 2007; ARCHE 2010
Invertebrate	*Enchytraeus albidus* (white worm)	28 to 42-d EC_{10}	Reproduction	8.5 (geomean; n=2)	Amorim et al. 2012
Plant (monocot)	*Elymus lanceolatus* (northern wheatgrass)	21-d IC_{20}	Emergence	9.6	Anaka et al. 2008
Plant (monocot)	*Avena sativa* (oat)	14-d EC_{10}	Shoot biomass	11	Förster and Becker 2009

Plant (dicot)	*Medicago sativa* (alfalfa)	45-d NOEC	Yield shoot	13.35 (geomean; n=12)	Gestring and Soltanpour 1987
Plant (dicot)	*Brassica napus* (rapeseed)	14-d EC_{10}	Shoot biomass	13.9	Förster and Becker 2009
Invertebrate	*Enchytraeus luxuriosus* (earthworm)	28-d EC_{10}	Reproduction	17	Moser and Becker 2009d
Invertebrate	*Enchytraeus crypticus* (earthworm)	28-d EC_{10}	Reproduction	22.5	Moser and Becker 2009c
Invertebrate	*Hypoaspis aculeifer* (predatory mite)	14-d EC_{10}	Reproduction	22.7	Moser and Scheffczyk 2009
Invertebrate	*Onychiurus folsomi*	35-d EC_{20}	Reproduction	24.1 (geomean; n=2)	ESG International Inc. and Aquaterra Environmental Consulting Ltd. 2003
Invertebrate	*Eisenia andrei* (earthworm)	56 to 63-d IC_{20}	Reproduction (juvenile dry mass)	24.8 (geomean; n=6)	Stantec Consulting Ltd. and Aquaterra Environmental Consulting 2004
Plant (tree)	*Picea glauca* (white spruce)	35-d IC_{25}	Root length	27.7 (geomean; n=3)	Environment Canada 2014c
Plant (tree)	*Betula papyrifera* (paper birch)	28-d IC_{25}	Root length	28.25 (geomean; n=3)	Environment Canada 2014c
Plant (monocot)	*Calamagrostis canadensis* (bluejoint reedgrass)	14-d IC_{25}	Root length	36.45 (geomean; n=4)	Environment Canada 2014c
Plant (tree)	*Populus tremuloides* (white poplar)	21-d IC_{25}	Root length	42.7 (geomean; n=3)	Environment Canada 2014c

Invertebrate	*Poecilus cupreus* (ground beetle)	21-d EC_{10}	Feeding rate	47.5	Moser and Becker 2009e
Plant (eudicot)	*Solidago canadensis* (Canada goldenrod)	21-d IC_{25}	Shoot length	48.1 (geomean; n=3)	Environment Canada 2014c
Invertebrate	*Dendrodrilus rubidus* (earthworm)	56-d IC_{25}	Reproduction	58.8 (geomean; n=2)	Environment Canada 2014c
Plant (tree)	*Picea mariana* (black spruce)	35-d IC_{25}	Root length	60.2 (geomean; n=5)	Environment Canada 2014c
Plant (tree)	*Pinus banksiana* (Jack pine)	14-d IC_{25}	Root length	61.1 (geomean; n=3)	Environment Canada 2014c
Invertebrate	*Eisenia fetida* (tiger worm)	56-d EC_{10}	Reproduction	70.1	Moser and Becker 2009a
Invertebrate	*Caenorhabditis elegans* (nematode)	4-d EC_{10}	Reproduction	86.7	Moser and Becker 2009b

Abbreviations: EC_x, the concentration of a substance that is estimated to cause some effect on x% of the test organisms; IC_x, the concentration of a substance that is estimated to cause some inhibition where the response is on x% of the test organisms; NOEC, no-observed-effect concentration

Appendix D. Estimated exposure from environmental media, food, and drinking water

Table D-1. General human exposure factors for different age groups in scenarios[a]

Age groups	Body weight (kg)	Inhalation rate (m^3/day)	Soil ingestion rate (µg/day)	Dust ingestion rate (µg/day)
0 to 5 months	6.3	3.7	N/A	21.6
6 to 11 months	9.1	5.4	7.3	27.0
1 year	11	8.0	8.8	35.0
2 to 3 years	15	9.2	6.2	21.4
4 to 8 years	23	11.1	8.7	24.4
9 to 13 years	42	13.9	6.9	23.8
14 to 18 years	62	15.9	1.4	2.1
Adults (19+)	74	15.1	1.6	2.6

[a] Health Canada [modified 2022b]

Probabilistic dietary intake estimates

Estimates were derived by the Food Directorate of Health Canada in 2013. Given that boron is naturally present in many foods at background levels that are generally consistent over time and that there have been minimal changes in the consumption patterns of people in Canada since 2013, particularly in the foods that contribute most to dietary exposure (fruit, fruit juice, vegetables), there is confidence that levels of dietary exposure to boron today is highly comparable to those estimated in 2013. Where possible, the CFIA imported and domestic mean boron concentration values were combined. Most food items sampled and analyzed by the CFIA had high percentages of positive samples (80%), that is, samples measured above the limit of quantitation. The samples that had relatively few positives were generally meats and eggs. Only positive samples were included in the dietary exposure estimates in Tables D-2 and D-3. Some foods for which the CFIA had no data but that were reported in the Agency for Toxic Substances and Disease Registry (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 US EPA's Health Effects Support Document for Boron published in 2008, which indicated the median value for 10 fish samples. For each of the 500 iterations and each food cited in the 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 age-sex group and each distribution of intakes were calculated using the Software for Intake Distribution Estimation 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 when available and were used to adjust intakes for body weight. For infants under 2 years of age, body weights from the US National Health and Nutrition Examination Survey were used. The estimates for the 0- to 6-month-old age group generated using this method were considered too unreliable to publish, in accordance with Statistics Canada requirements for the publication of statistical analysis using CCHS consumption data.

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).

Table D-2. Percentiles of usual dietary intakes (µg B/kg bw/day) for boron for the general population in Canada from food and water

Sex/age group	Median µg/kg bw/day (95% CI)	95th percentile µg/kg bw/day (95% CI)
M/F: 6 to 12 months	50.9 (44.6, 63.0)	82.6 (68.7, 119.5)
M/F: 1 to 3 yrs	91.7 (89.0, 94.8)	182.6 (173.3, 198.3)

Sex/age group	Median µg/kg bw/day (95% CI)	95th percentile µg/kg bw/day (95% CI)
M/F: 4 to 8 yrs	63.6 (62.3, 65.2)	121.7 (116.2, 129.2)
M: 9 to 13 yrs	37.8 (36.7, 39.1)	77.2 (72.9, 87.4)
F: 9 to 13 yrs	36.2 (35.0, 37.5)	70.5 (65.9, 80.5)
M: 14 to 18 yrs	26.2 (25.4, 27.1)	53.2 (49.8, 59.1)
F: 14 to 18 yrs	25.4 (24.6, 26.2)	52.0 (48.5, 58.0)
M: 19 to 30 yrs	23.0 (22.1, 24.2)	45.0 (41.2, 53.5)
F: 19 to 30 yrs	24.7 (23.8, 25.9)	48.6 (44.7, 54.6)
M: 31 to 50 yrs	20.8 (20.0, 21.7)	43.3 (39.6, 51.1)
F: 31 to 50 yrs	23.4 (22.6, 24.3)	51.2 (48.0, 59.7)
M: 51 to70 yrs	21.1 (20.5, 21.8)	43.7 (40.9, 49.0)
F: 51 to 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)

Abbreviations: 95% CI, 95% confidence interval (lower, upper); M/F, male/female; M, male; F, female; yrs, years

Table D-3. Average estimates of daily intake (µg/kg bw/day) of boric acid by the general population in Canada through environmental media and food

Route of exposure	0 to 5 m human milk-fed[a]	0 to 5 m formula-fed[b]	6 to 11 m	1 yr	2 to 3 yrs	4 to 8 yrs	9 to 13 yrs	14 to 18 yrs	Adult 19+ yrs
Air[c]	0.0032	0.0032	0.0032	0.0039	0.0033	0.0026	0.0018	0.0014	0.0011
Food, drinking water[d]	3.5	15.7	50.9	91.7	91.7	63.6	37.8	26.2	24.7
Soil[e]	N/A	N/A	2.6×10^{-8}	2.6×10^{-8}	1.4×10^{-8}	1.2×10^{-8}	5.4×10^{-8}	7.5×10^{-8}	7.1×10^{-8}
Dust[f]	2.2×10^{-7}	2.2×10^{-7}	1.9×10^{-7}	2.1×10^{-7}	9.3×10^{-8}	6.9×10^{-8}	3.7×10^{-8}	2.2×10^{-9}	2.3×10^{-9}
Total[g]	3.6	15.7	50.9	91.7	91.7	63.6	37.8	26.2	24.7

Abbreviations: N/A, not applicable; m, months; yr(s), year(s)

[a] Human milk-fed infants are assumed to consume solely human milk for 6 months. Human milk-fed infants 0 to 5 months old are assumed to consume on average 0.744 L human milk per day, and human milk is assumed to be the only dietary source for infants under 6 months old (Health Canada 2018b). The estimates incorporated an average concentration of 30 µg/L, which was measured in human milk in women from St. John’s, Newfoundland (Hunt et al. 2004).

[b] Exclusively formula-fed infants 0 to 5 months old were assumed to consume 0.826 L of infant formula per day, and formula is assumed to be the only dietary source for infants under 6 months old (Health Canada 2018b). A boron concentration of 120 µg/L, measured in ready-to-eat infant formula in the US (Hunt and Meacham 2001, supplemental), was incorporated into dietary estimates for 0- to 5-month-olds.

[c] Intake estimated using a median 24-hour personal air sample PM_{10} concentration of 5.38 ng/m^3 (n=93), measured in Windsor, Ontario (Rasmussen et al. 2022, Table 2 Appendix S7). Personal air data are considered to be most representative of air concentrations in the breathing zone.

[d] Median dietary intake estimates from Table D-2 above were used. Age group data were aligned as best possible. Where estimates exist for both sexes, the highest median value was incorporated into the estimate of daily intake.

[e] Intake based on the average concentration of total boron in US soils (33 µg/g) (USGS 1984); adequate Canadian data were not available.

[f] Intake based on the median national baseline concentration of bioaccessible boron,65 µg/g, measured in 1,025 homes in the Canadian House Dust Study (Rasmussen 2013).

[g] General human exposure factors for body weight, inhalation rate, and soil and dust ingestion intake were used to derive the estimates of exposure. Factors are presented in Table D-1.

Appendix E. Exposure estimates from products

Table E-1. Arts and crafts materials and toys: exposure estimates (µg/kg bw/day) and MOEs for boric acid (in boron equivalents)

Scenario	Age group (years)	Dermal exposure	Inhalation exposure	Oral exposure	Combined exposure	Frequency of use[a]	MOE[b]
Homemade modelling clay and slime – handling	Infant 1 year	18.9	N/A	92.4	111.3	Frequent/ daily	26
Commercial modelling clay and slime – handling	Infant 1 year	7.1	N/A	34.6	41.7	Frequent/ daily	70
Homemade crystals – mixing + handling	4 to 8	77.4	0.086	39.4	117.0	Infrequent/ intermittent	82
Craft paint	Infant 1 year	241.1	N/A	202.6	443.7	Frequent/ daily	7
Oil paint	14 to 18	0.57	N/A	N/A	0.57	Infrequent/ intermittent	16,950
Markers	Infant 1 year	N/A	N/A	0.23	0.23	Frequent/ daily	12,429
Craft glue	Infant 1 year	1.3	N/A	63.6	64.9	Frequent/ daily	45
Coloured sand	Infant 1 year	N/A	N/A	4.8	4.8	Frequent/ daily	608

Abbreviations: N/A, not applicable; MOE, margin of exposure

[a] Frequent use is defined as more than 1x/week but reoccurring; infrequent use is defined as less than 1x/week; and intermittent use is limited to less than one week of continued exposure.

[b] MOE = NOAEL 9.6 (mg/kg bw/day) for acute (infrequent/intermittent use) / exposure (µg/kg bw/day) * conversion mg/µg. MOE = BMDL 2.9 (mg/kg bw/day) for chronic (frequent/daily use) exposure / exposure (µg/kg bw/day) * conversion mg/µg. There may be differences in MOEs due to rounding. Target MOE is 300.

Table E-2. Cleaning products: exposure estimates (µg/kg bw/day) and MOEs for boric acid (in boron equivalents)

Scenario	Dermal exposure	Inhalation exposure	Oral exposure	Combined exposure	Frequency of use[a]	MOE[b]
Air freshener (1 year) – aerosol	N/A	8.7	N/A	N/A	Frequent/ daily	333
Abrasive powder	450	0.0022	N/A	450.0	Frequent/ daily	6
General purpose cleaner – powder	730	0.018	N/A	730.0	Frequent/ daily	4
General purpose cleaner and disinfectant – liquid	0.0015 (pour) + 3.2 (wipe)	N/A	N/A	3.2	Frequent/ daily	892
Carpet spot remover – spray	1.2	0.01	N/A	1.2	Infrequent/ intermittent	7,934
Carpet spot remover – powder	150	0.018	N/A	150.0	Infrequent/ intermittent	64
Floor cleaner – powder hand/mop	92 (apply)	0.0089 (pour)	N/A	92.0	Frequent/ daily	32
Floor cleaner – powder – post-app (1 year)	34.8	N/A	26.1	60.9	Frequent/ daily	48
Floor cleaner and disinfectant – liquid hand/mop	0.0015 (pour) + 0.22 (apply)	N/A	N/A	0.22	Frequent/ daily	13,302
Floor cleaner and disinfectant – liquid post-app (1 year)	0.082	N/A	0.06	0.14	Frequent/ daily	20,148
Dishes – hand wash	24.4	0.018	N/A	24.4	Infrequent/ intermittent	393

Scenario	Dermal exposure	Inhalation exposure	Oral exposure	Combined exposure	Frequency of use[a]	MOE[b]
china, powder						
Dishes – ingestion of oral residue from china	N/A	N/A	25.0	25.0	Infrequent/ intermittent	384
Dishes – dishwasher, liquid	0.12	N/A	N/A	0.12	Frequent/ daily	24,167
Laundry – pre-wash spot remover, liquid	9.4	N/A	N/A	9.4	Frequent/ daily	309
Laundry – hand wash from powder (load + wash + hanging)	15.2 (wash) + 76 (hang)	0.018 (pour)	N/A	91.3	Frequent/ daily	32
Laundry – hand wash, powder, wearing clothes (1 year)	14.7	N/A	3.6	18.3	Frequent/ daily	158
Laundry – machine wash, powder (load + hang)	1.5 (hang)	0.018 (pour)	N/A	1.5	Frequent/ daily	1,911
Laundry – machine wash, powder, wearing clothes (1 year)	4.3	N/A	1.0	5.4	Frequent/ daily	542
Laundry – machine wash, liquid (pour cap + hang)	11 (load) + 0.15 (hang)	N/A	N/A	11.2	Frequent/ daily	260
Laundry – machine wash, liquid, wearing	0.43	N/A	0.10	0.54	Frequent/ daily	5,394

Scenario	Dermal exposure	Inhalation exposure	Oral exposure	Combined exposure	Frequency of use[a]	MOE[b]
clothes (1 year)						
Polish/ degreaser	13.0	N/A	N/A	13.0	Infrequent/ intermittent	738
Toilet – powder	N/A	0.0089 (pour)	N/A	0.0089	Frequent/ daily	324,402

Abbreviations: N/A, not applicable; MOE, margin of exposure

[a] Frequent use is defined as more than 1x/week but reoccurring; infrequent use is defined as less than 1x/week; and intermittent use is limited to less than one week of continued exposure.

[b] MOE = NOAEL 9.6 (mg/kg bw/day) for acute (infrequent/intermittent use) / exposure (µg/kg bw/day) * conversion mg/µg. MOE = BMDL 2.9 (mg/kg bw/day) for chronic (frequent/daily use) exposure / exposure (µg/kg bw/day) * conversion mg/µg. There may be differences in MOEs due to rounding. Target MOE is 300.

Table E-3. DIY products - adhesive and sealants, automotive maintenance, home maintenance, and paints and coatings: exposure estimates (µg/kg bw/day) and MOEs (in boron equivalents)

Scenario	Dermal exposure	Inhalation exposure	Combined exposure	MOE[a]
Sealant, caulking	24.8	N/A	24.8	388
Automotive repair paste, filler	1.1	N/A	1.1	8,648
Automotive polish paste	9.6	N/A	9.6	10,03
Tire mounting paste	0.12	N/A	0.12	78,320
Synthetic brake fluid	2.4	N/A	2.4	39,73
Wood glue	0.19	N/A	0.19	50,775
Nail hole filler	1.1	N/A	1.1	8,648
Wood cleaner, brush	8.3	N/A	8.3	1,161
Rust paint, aerosol spray	9.8	16.0	25.8	372
Rust paint, brush	23.6	N/A	23.6	407
Rust paint, airless sprayer	50.8	11.1	61.9	155

Abbreviations: N/A, not applicable; MOE, margin of exposure

[a] MOE = NOAEL 9.6 (mg/kg bw/day) / exposure (µg/kg bw/day) * conversion mg/µg. All products are considered to result in acute exposure (infrequent, <1x/week, or intermittent, up to one week). There may be differences in MOEs due to rounding. Target MOE 300.

Table E-4. Flame retardant uses: dermal and inhalation exposure estimates (µg/kg bw/day) and MOEs (in boron equivalents)

Scenario	Age group (years)	Dermal exposure	Oral exposure (mouthing)	Combined exposure	MOE[a]

Sleeping on mattress or futon	Infant 0 to 5 m; adult	117.1; 24.2	N/A	117.1; 24.2	25; 120
Wearing sleepwear	Infant 0 to 5 m	0.30	0.0016	0.30	9,777

Abbreviations: N/A, not applicable; M, months; MOE, margin of exposure

[a] MOE = BMDL 2.9 (mg/kg bw/day) / exposure (µg/kg bw/day) * conversion mg/µg. These uses are anticipated to result in chronic (frequent or daily) exposure (>1x/week). There may be differences in MOEs due to rounding. Target MOE is 300.

Table E-5. Self-care products: dermal and inhalation exposure estimates (µg/kg bw/day) and MOEs (in boron equivalents) in cosmetics, natural health products, and non-prescription drugs

Scenario	Age group (years)	Dermal exposure	Inhalation exposure	Combined exposure	Frequency of use[a]	MOE[b]
Permanent hair colour (cosmetic)	14 to 18; adult	848.2; 161.8	N/A	191.9; 161.8	Infrequent/ intermittent	50; 60
Beard conditioner (cosmetic)	adult	6.0	N/A	6.0	Frequent/ daily	487
Hair gel (cosmetic)	4 to 8	6.6	N/A	6.6	Frequent/ daily	437
Hairspray - aerosol (cosmetic)	4 to 8	0.088	0.00092	0.088	Frequent/daily	32,781
Body soap - liquid (cosmetic and non-prescription drug)	4 to 8	2.7	N/A	2.7	Frequent/ daily	1,080
Baby wash (cosmetic)	0 to 5 months	0.16	N/A	0.16	Frequent/ daily	18,545
Body lotion (cosmetic)	4 to 8; adult	111.4; 66.6	N/A	111.4; 66.6	Frequent/ daily	26; 44
Foot lotion (cosmetic)	14 to 18	3.3	N/A	3.3	Frequent/ daily	890
Anti-itch and rash cream (NHP)	4 to 8	30.6	N/A	30.6	Infrequent/ intermittent	313
Anti-hemorrhoid cream (NHP)	4 to 8; adult	167.6; 52.1	N/A	167.6; 52.1	Infrequent/ intermittent	57; 184

Scenario	**Age group (years)**	**Dermal exposure**	**Inhalation exposure**	**Combined exposure**	**Frequency of use[a]**	**MOE[b]**
Massage oil (cosmetic)	4 to 8; adult	53.3; 27.9	N/A	53.3; 27.8	Infrequent/ intermittent	180; 344
Hair removal after-care (cosmetic)	9 to 13; adult	34.3; 25.2	N/A	34.3; 25.2	Frequent/ daily	84; 115
Facial exfoliant (cosmetic)	14 to 18	2.2	N/A	2.2	Frequent	1,301
Face makeup remover lotion (cosmetic)	4 to 8	8.4	N/A	8.4	Frequent	347
Face mask (cosmetic)	14 to 18	0.45	N/A	0.45	Infrequent/ intermittent	21,470
Face lotion (cosmetic)	adult	20.0	N/A	20.0	Frequent/ daily	145
Eyebrow tint (cosmetic)	14 to 18	0.37	N/A	0.37	Infrequent/ intermittent	25,728
Eyeshadow cream (cosmetic)	4 to 8	0.037	N/A	0.037	Frequent/ daily	79,368
Nail adhesive (cosmetic)	14 to 18	0.049	N/A	0.049	Infrequent/ intermittent	195,335
Nail adhesive (cosmetic)	14 to 18	N/A	0.0088 mg boron trifluoride monoetherate/m^3	N/A	Infrequent/ intermittent	28,11
Bath bomb (cosmetic)	4 to 8	0.78	N/A	0.78	Frequent/ daily	37,41

Abbreviations: N/A, not applicable; NHP, natural health product; MOE, margin of exposure

[a] Frequent use is defined as more than 1x/week but reoccurring; infrequent use is defined as less than 1x/week; and intermittent use is limited to less than one week of continued exposure.

[b] MOE = NOAEL 9.6 (mg/kg bw/day) for acute (infrequent/intermittent use) / exposure (µg/kg bw/day) * conversion mg/µg. MOE = BMDL 2.9 (mg/kg bw/day) for chronic (frequent/daily use) exposure / exposure (µg/kg bw/day) * conversion mg/µg. There may be differences in MOEs due to rounding. Target MOE is 300.

Table E-6. Self-care products: oral, ocular, and otic exposure estimates (µg/kg bw/day) and MOEs (in boron equivalents) in cosmetics, natural health products, and non-prescription drugs

Scenario	Age group (years)	Route	Exposure	Frequency of use[a]	MOE[b]
Multi-vitamin/mineral and workout supplements (NHP)	adults	oral	9.5	Frequent/ daily	307
Children’s multi-vitamin/mineral supplements (NHP)	4 to 8	oral	7.3	Frequent/ daily	399
Joint health products (NHP)	adults	oral	45.4	Frequent/ daily	64
Other oral supplements (NHP)	adults	oral	135.1	Frequent/ daily	21
Tooth whitener (cosmetic)	adults	oral	3.4	Frequent/ daily	853
Toothpaste (cosmetic)	9 to 13	oral	3.4	Frequent/ daily	844
Mouthwash (cosmetic)	4 to 8; adult	oral	17.2; 9.1	Frequent/ daily	168; 318
Lip moisturizer and/or SPF (cosmetic and non-prescription drug)	4 to 8	oral	3.4	Frequent/ daily	864
Eye drops (NHP and non-prescription drug), acute	adults	ocular	8.1	Infrequent/ intermittent	1,190
Eye drops (NHP and non-prescription drug), chronic	4 to 8; adult	ocular	10.3; 4.4	Frequent/ daily	283; 664
Contact lens solution (non-prescription drug)	9 to 13	combined (dermal + ocular)	1.2 (0.82 + 0.43)	Frequent/ daily	2,330
Eye wash (NHP)	4 to 8	combined (dermal + ocular)	3.7 (2.1 + 1.6)	Infrequent/ intermittent	2,608
Ear drops (non-prescription drug)	0 to 5 months	otic	16.7	Infrequent/ intermittent	576

Abbreviations: N/A, not applicable; NHP, natural health product; MOE, margin of exposure

[a] Frequent use is defined as more than 1x/week but reoccurring; infrequent use is defined as less than 1x/week; and intermittent use is limited to less than one week of continued exposure.

[b] MOE = NOAEL 9.6 (mg/kg bw/day) for acute (infrequent/intermittent use) / exposure (µg/kg bw/day) * conversion mg/µg. MOE = BMDL 2.9 (mg/kg bw/day) for chronic (frequent/daily use) exposure / exposure (µg/kg bw/day) * conversion mg/µg. There may be differences in MOEs due to rounding. Target MOE is 300.

Table E-7. Swimming pool and spa maintenance products: exposure estimates (µg/kg bw/day) and MOEs (in boron equivalents)

Scenario	Dermal exposure	Oral exposure	Inhalation exposure	Combined exposure	Use frequency[a]	MOE[b]
Homeowner application of powder	N/A	N/A	4.0	4.0	Infrequent/ intermittent	2,389
Homeowner application of granules	N/A	N/A	0.16	0.16	Infrequent/ intermittent	61,018
Swimming, child 4 to 8 years, adult	36.6; 8.8	312.3; 23.7	N/A	348.8; 32.5	Frequent/ daily	8; 89

Abbreviations: N/A, not applicable; MOE, margin of exposure

[a] Frequent use is defined as more than 1x/week but reoccurring; infrequent use is defined as less than 1x/week; and intermittent use is limited to less than one week of continued exposure.

[b] MOE = NOAEL 9.6 (mg/kg bw/day) for acute (infrequent/intermittent use) / exposure (µg/kg bw/day) * conversion mg/µg. MOE = BMDL 2.9 (mg/kg bw/day) for chronic (frequent/daily use) exposure / exposure (µg/kg bw/day) * conversion mg/µg. There may be differences in MOEs due to rounding. Target MOE is 300.

Appendix F. Detailed exposure tables

Exposure estimates were derived for multiple age groups; however, only estimates for the age groups with the highest exposure estimates are presented here. Body weights and inhalation rates used in the exposure estimates are presented in Table D-1. Daily estimates of exposure were based on a frequency of one time per day unless otherwise noted. Exposure estimates were derived using the highest concentration (weight fraction) of boron found per product type or scenario, unless otherwise noted. The concentration data were obtained through information submitted to Health Canada or publicly available information as described in section 8.2.3.

Exposure estimates were derived using various exposure models and algorithms including ConsExpo Web Model, ver. 1.0.7, updated February 18, 2020 (2020), the US EPA Residential SOPs (2012b), data from the PHED (Health Canada 2002a), the US EPA SWIMODEL (2003, 2016), and other algorithms.

Exposure estimates derived using unit exposure values were based on the following algorithm:

Exposure (µg/kg bw/day) = unit exposure value (µg/kg handled) * concentration boron (fraction) * amount product handled (kg/day) / body weight (kg)

PHED unit exposure values were found in Health Canada (2002a).

Dermal exposure from solid borax was not quantified since dermal absorption of solid borax is anticipated to be minimal relative to borax in solution. In addition, dermal exposure is anticipated to be minimal compared with inhalation exposure of solid borax. Dermal estimates reflect systemic absorption using either a fixed, fractional dermal absorption value of 10% (as described in section 8.1.2) or a permeability coefficient (Kp) of 5 × 10^{-4} cm/hour for boric acid (Wester et al. 1998b). A permeability coefficient was used for scenarios where there is prolonged immersion in a solution of boric acid, such as hand-washing dishes, bathing, or swimming in a pool.

Arts and crafts materials and toys

Exposure estimates for arts and crafts materials and toys were derived using the algorithms below, unless otherwise noted.

Dermal exposure (µg/kg bw/day) = weight fraction * product amount (µg/day) * dermal absorption (fraction) / body weight (kg)

Oral exposure (µg/kg bw/day) = boron concentration (fraction) * product amount (µg/day) / body weight (kg)

Table F-1. Arts and crafts materials and toys: detailed calculations and inputs for estimates of exposure to boric acid as boron equivalents

Scenario	Model and inputs	Exposure
Homemade and commercial modelling clay and slime – handling	Population: 1 year Concentration: 0.254% (homemade), 0.095% (commercial, arithmetic mean from Health Canada 2002b, 2004, 2009a, 2009b, 2017b, 2018a, 2019) **Dermal exposure from handling** Algorithm adapted from Park et al. 2018, den Braver et al. 2021, and Lim et al. 2022 Dermal exposure (µg/kg bw/day) = boron concentration (fraction) * exposure time (min/day) * skin adhesion factor (g/min/cm^2) * surface area (cm^2) * leaching from simulated sweat (fraction) * dermal absorption (fraction) / body weight (kg) Exposure time: 30 min/day (Park et al. 2018; den Braver et al. 2021) Skin adhesion factor: 0.0013 g/min/cm^3 (Guak et al. 2018; Park et al. 2018; den Braver et al. 2021; Lim et al. 2022)	Homemade: Dermal exposure 18.9 µg/kg bw/day Oral exposure 92.4 µg/kg bw/day Commercial: Dermal exposure 7.1 µg/kg bw/day Oral exposure 34.6 µg/kg bw/day

Scenario	Model and inputs	Exposure
	Surface area: 300 cm^2 (two hands) Leaching from simulated sweat: 7% (calculated from BfR 2005, where 0.1 g boric acid leached from clay containing 1.36 g [8%] boric acid) **Incidental ingestion when handling** Product amount ingested: 400 mg/day (default, RIVM 2008; SCHER 2016; Danish EPA 2020)	
Homemade crystals – mixing + handling	Population: 4 to 8 years **Inhalation exposure while mixing** Model: PHED Inhalation, mix/load wettable powder (excluding water soluble packaging) Unit exposure = 56.2 µg/kg handled (Health Canada 2002a) Concentration: 11.34% (powdered borax) Amount handled: 0.3114 kg (180 mL borax * 1.73 g/mL density) **Dermal exposure from mixing in water** Exposed area: 35.8 cm^2 (five fingertips) Concentration: 11.34% Product amount on skin: 0.157 g (0.01 cm thin film layer default from ConsExpo * exposed area, cm^2 * 180 mL borax * 1.73 g/cm^3 density / 709.8 mL water) **Incidental ingestion when handling** Concentration: 11.34% Product amount ingested: 8 mg/day (RIVM 2008; SCHER 2016)	Inhalation exposure 0.086 µg/kg bw/day Dermal exposure 77.4 µg/kg bw/day Oral exposure 39.4 µg/kg bw/day
Craft paint	Population: 1 year Concentration: 0.557% (gastric bioaccessible boron, Stopford 2013)	Dermal exposure 241.2 µg/kg bw/day Oral exposure

Scenario	Model and inputs	Exposure
	Product amount on skin: 4,762.5 mg/day (31.75 mg/cm^2 [Scott and Moore 2000] * exposed area of 2 palms, 150 cm^2) Product amount ingested: 400 mg/day (RIVM 2008; SCHER 2016)	202.6 µg/kg bw/day
Oil paint	Population: 14 to 18 years Concentration: 0.830% (gastric bioaccessible boron, Stopford 2013) Product amount on skin: 42.31 mg (50 mg [RIVM 2007], scaled adult to teen hand surface area, 910 to 770 cm^2)	Dermal exposure 0.57 µg/kg bw/day
Marker inks	Population: 1 year Concentration: 0.140% (gastric bioaccessible boron, Stopford 2013) Product amount ingested: 25 mg/day (100 µg/cm ink laydown rate * 25 cm ink line/day [personal communication from Art and Creative Materials Institute to the Existing Substances Risk Assessment Bureau, Health Canada, 2009; unreferenced]) This conservative estimate is considered to account for exposure via the dermal route.	Oral exposure 0.23 µg/kg bw/day
Craft glue	Population: 1 year Concentration: 0.180% (Stopford 2013, gastric bioaccessible boron) Product amount on skin: 0.08 g based upon default value for adult handling glue (RIVM 2022) Product amount ingested: 400 mg/day (RIVM 2008; SCHER 2016)	Dermal exposure 1.3 µg/kg bw/day Oral exposure 63.6 µg/kg bw/day
Coloured sand	Population: 1 year Concentration: 0.053% (gastric bioaccessible boron, Stopford 2013) Product amount ingested: 100 mg/day (RIVM 2008; SCHER 2016)	Oral exposure 4.8 µg/kg bw/day

Cleaning products

Exposure estimates for cleaning products were derived using ConsExpo Web (2020), the US EPA Residential SOPs (2012b), and PHED unit exposures (Health Canada

2002a) unless otherwise noted. For products with multiple possible application methods for a given use scenario (for example, washing floors by hand or by mop), the exposure estimates for the application method associated with the highest exposure are presented.

Concentration data were obtained from voluntary information submitted by stakeholders, a search of publicly available websites including material safety data sheets, and journal publications.

Table F-2. Cleaning products: detailed calculations and inputs for estimates of exposure to boric acid as boron equivalents

Scenario	Model and inputs	Exposure
Air freshener – automatic spray and aerosol	Population: 1 year **Inhalation exposure during spraying** ConsExpo Web (2021, v1.1.0) Fact Sheet: Air fresheners, home air fresheners, instant air refreshment sprays – aerosol can, inhaling non-volatile substances, infant bystanders Model: Inhalation, exposure to spray, spraying Spray duration: 4 sec Exposure duration: 4 hr Weight fraction: 0.11% Room volume: 20 m^3 (unspecified room) Room height: 2.5 m (standard room height) Ventilation rate: 0.6/hr (unspecified room) Inhalation rate: 8.0 m^3/day Mass generation rate: 2.0 g/s Airborne fraction: 0.8 Density: 0.96 g/cm^3 Inhalation cut-off diameter: 10 µm (HC refinement) Aerosol diameter: log-normal Median diameter (CV): 3.9 (0.65) µm Maximum diameter: 50 µm	Mean event concentration 0.072 mg/m^3 Inhalation exposure – spraying 8.7 µg/kg bw/day
Abrasive powder	Population: adult	Inhalation exposure – pouring

Scenario	Model and inputs	Exposure
	Application rate: 15 mL product on wet sponge **Inhalation exposure while pouring** Model: PHED M/L (mixing and loading) wettable powder (no water-soluble packaging [WSP]) Unit exposure = 56.2 µg/kg handled (Health Canada 2002a) Concentration of boron: 11.34% Amount handled: 0.026 kg/day (15 mL product * 1.73 g/mL density) **Dermal exposure during use** ConsExpo Web (2020) Fact Sheet: Cleaning and washing, abrasives, abrasive powder, application – rubbing Model: Direct product contact – instant application Exposed area: 227.5 cm^2 (palm of hand) Weight fraction: 11.34% Product amount: 2.95 g (0.01 cm thin film default from ConsExpo * exposed area, cm^2) * 15 mL product * 1.73 g/mL density / 20 mL water to wet sponge (RIVM 2018, 9.1.2)	0.0022 µg/kg bw/day Dermal exposure – rubbing 450 µg/kg bw/day
General purpose cleaner – powder for use on walls, refrigerator, garbage pail	Population: adult **Application rate:** 2.5% boron, 120 mL product per 950 mL water **Inhalation exposure during pouring of powder into bucket** Model: PHED M/L wettable powder (no WSP) Unit exposure = 56.2 µg/kg handled (Health Canada 2002a) Concentration of boron: 11.34% Amount handled: 0.208 kg/day (120 mL product * 1.73 g/mL density)	Inhalation exposure – pouring 0.018 µg/kg bw/day Dermal exposure – wiping 730 µg/kg bw/day

Scenario	Model and inputs	Exposure
	Dermal exposure while using diluted liquid – wash/wipe by hand ConsExpo Web (2020) Fact Sheet: Cleaning and washing, all purpose cleaners, all purpose cleaning spray, application – spraying (non-volatile substances) Model: Dermal, direct product contact – instant application Exposed area: 2,185 cm^2 (hands and forearms) Weight fraction: 11.34% Product amount = 4.8 g (0.01 cm thin film default from ConsExpo * exposed area, cm^2) * 120 mL product * 1.73 g/mL density / 950 mL dilution in water Note: inhalation exposure to boron during washing with diluted product is expected to be negligible	
General purpose cleaner and disinfectant – liquid Sentinel scenario covering exposure from general purpose cleaner – putty and spray	Population: adult **Dermal exposure during pouring** ConsExpo Web (2020) Fact Sheet: Cleaning and washing, all purpose cleaners, all purpose cleaning liquid, mixing and loading Model: Dermal direct product contact – instant application Exposed area: NA Weight fraction substance: 0.011% Amount applied: 0.01 g (default) **Dermal exposure during wipe/rinse** ConsExpo Web (2020) Fact Sheet: Cleaning and washing, all purpose cleaners, all purpose cleaning liquid, application – cleaning Model: Dermal, direct product contact – instant application	Dermal exposure (pour) 0.0015 µg/kg bw/day Dermal exposure (wipe) 3.2 µg/kg bw/day

Scenario	Model and inputs	Exposure
	Exposed area: 2,185 cm^2 (hands and forearms) Weight fraction substance: 0.011% Product amount: 21.85 g (0.01 cm thin film default from ConsExpo * exposed area, cm^2 * 1 g/mL density)	
Carpet – spot remover – aerosol spray	Population: adult **Inhalation exposure** ConsExpo Web (2020) Fact Sheet: Cleaning and washing, floor, carpet and furniture products, floor polish spray, application – spraying (non-volatile substances) Model: Inhalation exposure to spray – spraying (non-volatile substances) Spray duration: 1.65 s (adjusted from default of 33 s for 10 m^2 - floor polish, to an area of 0.1 m^2 for a spot) Exposure duration: 15 min (exposure duration from carpet spot remover exposure to vapour–evaporation– constant release area model, RIVM 2018, section 11.2.3.1) Weight fraction: 0.15% Room volume: 58 m^3 Room height: 2.5 m Ventilation rate: 0.5/hr Inhalation rate: 15.1 m^3/day Mass generation rate: 1.2 g/s (default for aerosol) Airborne fraction: 0.3 Density non-volatile: 1.8 g/cm^3 Inhalation cut-off diameter: 10 µm (HC default) Aerosol diameter distribution type: log-normal Median diameter (CV): 10.8 (0.81) µm Maximum diameter: 50 µm	Mean event concentration 0.0047 mg/m^3 Inhalation exposure – spraying 0.010 µg/kg bw/day Dermal exposure 1.2 µg/kg bw/day

Scenario	Model and inputs	Exposure
	Dermal exposure ConsExpo Web (2020) Fact Sheet: Cleaning and washing, floor, carpet and furniture products, carpet spot remover Model: Dermal, direct product contact – instant application loading Surface area: NA Weight fraction substance: 0.15% Product amount: 0.6 g (default)	
Carpet – spot remover – powder	Population: adult **Application rate:** 5% boron, 120 mL product per 475 mL water **Inhalation exposure while pouring** Model: PHED, M/L wettable powder (no WSP) Unit exposure = 56.2 µg/kg handled (Health Canada 2002a) Concentration of boron: 11.34% Amount handled: 0.208 kg/day (120 mL product * 1.73 g/mL density) **Dermal exposure while using diluted liquid** ConsExpo Web (2020) Fact Sheet: Cleaning and washing, floor, carpet and furniture products, carpet spot remover Model: Dermal, direct product contact – instant application Exposed area: 227.5 cm^2 (palm of one hand, a modification of the ConsExpo default) Weight fraction substance: 11.34% Product amount: 0.99 g (0.01 cm thin film default from ConsExpo * exposed area, cm^2 * (120 mL product * 1.73 g/mL density) / 475 mL dilution in water)	Inhalation exposure 0.018 µg/kg bw/day Dermal exposure 150 µg/kg bw/day

Scenario	Model and inputs	Exposure
Floor cleaning – by hand or mopping Powder and liquid	**Application rate:** powder: 0.3% boron, 60 mL product per 3.8 L water. Liquid: 0.011% boron, liquid **Inhalation exposure while pouring** Population: adult Model: PHED M/L wettable powder (no WSP) Unit exposure = 56.2 µg/kg handled (Health Canada 2002a) Concentration of boron: 11.34% (powder) Amount handled: 0.104 kg/day (60 mL product * 1.73 g/mL density) **Dermal exposure while pouring liquid** Population: adult ConsExpo Web (2020) Fact Sheet: Cleaning and washing, all purpose cleaners, all purpose cleaning liquid, mixing and loading Model: Dermal, direct product contact Weight fraction: 0.011% (liquid) Product amount: 0.01 g **Dermal exposure while mopping or cleaning by hand** Population: adult ConsExpo Web (2020) Fact Sheet. Cleaning and washing, floor, carpet and furniture products, floor cleaning liquid, application – cleaning Model: Dermal, direct product contact – instant application Exposed area: 2,185 cm^2 (hands and forearms) Weight fraction: 11.34% powder, 0.011% liquid Product amount = 0.6 g powder (0.01 cm thin film default from	Inhalation exposure – apply Powder: 0.0089 µg/kg bw/day Liquid: N/A Dermal exposure – pour Powder: N/A Liquid: 0.0015 µg/kg bw/day Dermal exposure – apply Powder: 92 µg/kg bw/day Liquid: 0.22 µg/kg bw/day Dermal exposure – post-application Powder: 34.8 µg/kg bw/day Liquid: 0.082 µg/kg bw/day Oral exposure – hand-to-mouth post-application powder: 26.1 µg/kg bw/day liquid: 0.06 µg/kg bw/day

Scenario	Model and inputs	Exposure
	ConsExpo * exposed area, cm^2 * 60 mL product * 1.73 g/mL density) / 3,800 mL dilution in water) or 1.46 g liquid (0.01 cm thin film default from ConsExpo * exposed area, cm^2 * density 1 g/mL) **Post-application dermal exposure** Population: 1 year US EPA Residential SOPs (2012b) Indoor Environments, Post-Application Dermal Exposure (hard surfaces, algorithms 7.16, 7.17, 7.18 adapted) Dermal deposition (mg) = boron concentration (fraction) * surface residue product (mL/m^2) * floor-to-skin transfer efficiency (fraction) * transfer coefficient (cm^2/hr) * exposure duration (hr) * conversion factors * density (g/mL) Dermal intake (mg/kg bw/day) = [dermal deposition (mg) * dermal absorption (fraction)] / body weight (kg) Concentration: 0.3% powder (104 g product / 3,800 mL dilution in water * 11.34% boron), 7×10^{-4}% liquid (250 mL/3750 mL dilution in water * 0.011% boron) Surface residue product: 40 mL product/m^2 (default, RIVM 2018) Floor-to-skin transfer efficiency: 0.08 Transfer coefficient: 1 927 cm^2/hr (adjusted for child surface area (5 300 cm^2/18 700 cm^2) from default adult transfer coefficient of 6,800 cm^2/hr for hard surfaces and carpets, US EPA 2012b) Exposure duration: 2 hrs	

Scenario	Model and inputs	Exposure
	Density: 1 g/mL (primarily water) **Oral exposure post-application** Population: 1 year US EPA Residential SOPs (2012b) Indoor Environments, Post-application Non-Dietary Ingestion Exposure Assessment Hand to Mouth, algorithm 7.20 Fraction of substance on hands compared to total surface residue from jazzercise study: 0.15 Surface areas of both hands: 300 cm^2 Fraction of hand surface area mouthed per event: 0.13 fraction/event Surface area of one hand: 150 cm^2 Exposure time: 2 hr/day Number of replenishment intervals per hr: 4 Saliva extraction factor: 0.48 Frequency of hand-to-mouth events per hour: 20 events/hr	
Dishes (china) – hand wash with powder formulation	Population: adult **Application rate:** 0.6% boron, 120 mL product per 3.8 L water **Inhalation exposure while loading powder** Model: PHED M/L wettable powder (no WSP) Unit exposure = 56.2 µg/kg handled (Health Canada 2002a) Concentration: 11.34% Amount handled: 0.208 kg/day (120 mL product * 1.73 g/mL density) **Dermal exposure while handwashing in dilute liquid** Dermal exposure (µg/kg bw/day) = concentration, µg/mL * duration,	Inhalation exposure – loading 0.018 µg/kg bw/day Dermal exposure – washing 24 µg/kg bw/day Oral exposure – ingestion 25 µg/kg bw/day

Scenario	Model and inputs	Exposure
	hr/day * Kp, cm/hr * exposed area, cm^2 / body weight, kg This algorithm was used as a refinement over the ConsExpo Web (2020) model. Concentration: 6 195 µg/mL (120 mL product * 1.73 g/mL density * 10 00 000 conversion g to µg / 3 800 mL dilution in water) Duration: 16 min/day (RIVM 2018, default for handwashing dishes, emission duration, 7.3.1) Exposed area: 2,185 cm^2 (hands and forearms) Kp: 0.0005 cm/hr for boric acid (Wester et al. 1988) **Ingestion of residue** ConsExpo Web (2020) Factsheet: Cleaning and washing, Dishwashing products, Manual dishwashing liquid, Post-application residues on tableware Model: Oral, direct product contact – direct oral intake Weight fraction: 11.34% Amount ingested: 0.01623 g (from RIVM 2018, where 5.5×10^{-5} mL/cm^2 of water on dishes * 5,400 cm^2 surface area of tableware * 120 mL product * 1.73 g/mL density / 3,800 mL dilution in water)	
Dishes – automatic dishwasher, loading liquid Sentinel scenario covering exposure from powder and tablet dishwasher products	**Dermal exposure while loading liquid** ConsExpo Web (2020) Fact Sheet: Cleaning and washing, dish washing products, dishwashing machine liquid, mixing and loading Model: Dermal, direct product contact – instant application Exposure area: NA Weight fraction: 0.87% Product amount: 0.01 g (default)	Dermal exposure – loading 0.12 µg/kg bw/day

Scenario	Model and inputs	Exposure
Laundry – pre-wash spot remover, liquid product Sentinel scenario covering exposure to laundry pre-wash spot application spray	Population: adult **Dermal exposure while spot treating** ConsExpo Web (2020) Fact Sheet: Cleaning and washing, laundry products, spot remover liquid, application – spot treatment Model: Dermal, direct product contact – instant application Exposed area: NA Weight fraction: 2.15% Product amount: 0.325 g (default)	Dermal exposure – washing 9.4 µg/kg bw/day
Laundry – pre-wash, hand wash - powder	**Application rate:** 0.6% boron, ½ cup product (120 mL) per 1 gallon (3.79 L) water **Inhalation exposure while pouring** Population: adult Model: PHED M/L wettable powder (no WSP) Unit exposure = 56.2 µg/kg handled (Health Canada 2002a) Concentration of boron: 11.34% Amount handled: 0.208 kg/day (120 mL product * 1.73 g/mL density) **Dermal exposure while handwashing** Population: adult Dermal exposure (µg/kg bw/day) = concentration, µg/mL * duration, hr/day * Kp, cm/hr * exposed area, cm^2 / body weight, kg Concentration: 6 195 µg/mL (120 mL product * 1.73 g/mL density * 1 000 000 conversion g to µg / 3 800 mL dilution in water) Duration: 10 min/day (RIVM 2018, default for handwashing clothes, 6.2.3)	Inhalation exposure – loading 0.018 µg/kg bw/day Dermal exposure – handwashing 15.2 µg/kg bw/day Dermal exposure – hanging 76 µg/kg bw/day Dermal exposure – wearing clothes, 1 year old 14.7 µg/kg bw/day Oral exposure – mouthing textiles, 1 year old 3.6 µg/kg bw/day

Scenario	Model and inputs	Exposure
	Exposed area: 2,185 cm^2 (hands and forearms) Kp: 0.0005 cm/hr for boric acid (Wester et al. 1988) **Dermal exposure from hanging hand-washed laundry** Population: adult ConsExpo Web (2020) Fact Sheet: Cleaning and washing, laundry products, hand washing powder – regular, application – hanging hand-washed laundry Model: Dermal, direct product contact – instant application Exposed area: 910 cm^2 (two hands) Product amount: 0.5 g (0.01 cm thin film default from ConsExpo * exposed area, cm^2) * 120 mL product * 1.73 g/mL density) / 3,800 mL dilution in water) **Post-use dermal exposure from wearing clothes** Population: 1 year US EPA Residential SOPs (2012b): Impregnated materials, textiles (algorithm 9.1, 9.2, 9.3) Boron concentration: 11.34% Weight fraction of product on textile: 3.6×10^{-3} (modified RIVM 2018 defaults for leachable fraction – adjust 13 g residual from 150 g product [Table 6.6, used residual from second wash to represent a rise after pre-soak] for 208 g product [120 mL product * 1.73 g/mL density]. Used adjusted residue [18 g] to calculate weight fraction of product on textile [18 g residue/5000 g textiles].) Material weight: surface area Density: 20 mg/cm^2 (cotton)	

Scenario	Model and inputs	Exposure
	Surface area residue concentration: 0.0082 mg/cm^2 Surface area: 4,130 cm^2 (Health Canada body surface area minus head and hands) Fraction of body exposed: 0.8 (default skin-contact factor, RIVM 2018) Material-to-skin transfer efficiency: 0.06 (textiles or carpeting, US EPA 2012b) **Post-use oral exposure from wearing clothes** Population: 1 year Exposure (mg/kg bw/day) = surface residue (mg/cm^2) * surface area mouthed (cm^2) * saliva extraction factor/ body weight Surface residue concentration: 0.0082 mg/cm^2 Surface area mouthed: 10 cm^2 Saliva extraction factor: 0.48	
Laundry – machine wash – powder Sentinel scenario covering exposure to machine wash tablet	Population: adult **Application rate:** 11.34% boron, 120 mL product per load **Inhalation exposure while pouring** Model: PHED M/L wettable powder (no WSP) Unit exposure = 56.2 µg/kg handled (Health Canada 2002a) Concentration boron: 11.34% Amount handled: 0.208 kg (120 mL product * 1.73 g/mL density) **Dermal exposure from hanging laundry** ConsExpo Web (2020) Fact Sheet: Cleaning and washing, laundry	Inhalation exposure – loading 0.018 µg/kg bw/day Dermal exposure – hanging 1.5 µg/kg bw/day Dermal exposure – wearing clothes, 1 year 4.3 µg/kg bw/day Oral exposure – mouthing textiles, 1 year 1.0 µg/kg bw/day

Scenario	Model and inputs	Exposure
	products, machine-washing powder regular, hanging machine-washed laundry Model: Dermal, direct product contact – instant application Exposed area: NA Weight fraction: 11.34% Product amount: 9.6 mg (adjusted default of 6.9 mg for 150 g of washing detergent for use of 208 g product [from 120 mL product * 1.73 g/mL density]) **Post-use dermal exposure from wearing clothes** Population: 1 year US EPA Residential SOPs (2012b): Impregnated materials, textiles (algorithm 9.1, 9.2, 9.3) Boron concentration: 11.34% Weight fraction of product on textile: 1.054 × 10^{-3} (modified RIVM 2018 [Table 6.6] defaults for leachable fraction – adjust 3.8 g residual from 150 g product for 208 g of product [120 mL product * 1.73 g/mL density]. Used adjusted residual [5.27 g] to calculate adjusted weight fraction of product on textile [5.27 g] residual/5000 g textiles].) Material weight: 20 mg/cm^2 (cotton) Surface residue concentration: 0.00239 mg/cm^2 Surface area: 4,130 cm^2 (body minus head and hands) Fraction of body exposed: 0.8 (default skin-contact factor, RIVM 2018) Material-to-skin transfer efficiency: 0.06 (textiles or carpeting, US EPA 2012b)	

Scenario	Model and inputs	Exposure
	Post-use oral exposure from wearing clothes Population: 1 year Exposure (mg/kg bw/day) = surface residue (mg/cm^2) * surface area mouthed (cm^2) * saliva extraction factor/ body weight Surface residue concentration: 0.00239 mg/cm^2 Surface area mouthed: 10 cm^2 Saliva extraction factor: 0.48	
Laundry – machine wash liquid	Population: adult **Dermal exposure while pouring from cap** ConsExpo Web (2020) Fact Sheet: Cleaning and washing, laundry products, machine-washing liquid – regular, mixing and loading – pouring with caps Model: Dermal, direct product contact – instant application Exposed area: 53 cm^2 (fingertips and phalange holding the cap, default) Weight fraction: 1.58% Product amount: 0.53 g (0.01 cm thin film default from ConsExpo * exposed area, cm^2 * 1 g/cm^3 density [default]) **Dermal exposure from hanging machine-washed laundry** ConsExpo Web (2020) Fact Sheet: Cleaning and washing, laundry products, machine-washing liquid regular, application – hanging machine-washed laundry Model: Dermal, direct product contact – instant application Exposed area: NA Weight fraction: 1.58% Product amount: 6.9 mg (default)	Dermal exposure – load, pouring from cap 11 µg/kg bw/day Dermal exposure – hanging 0.15 µg/kg bw/day Dermal exposure – wearing clothes, 1 year 0.43 µg/kg bw/day Oral exposure – mouthing textiles, 1 year 0.10 µg/kg bw/day

Scenario	Model and inputs	Exposure
	Post-use dermal exposure from wearing clothes Population: 1 year US EPA Residential SOPs (2012b): Impregnated materials, textiles (algorithm 9.1, 9.2, 9.3) Boron concentration: 1.58% Weight fraction of product on textile: 0.00076 (used RIVM 2018 [Table 6.7] defaults for leachable fraction – 3.8 g residual from 150 g product in 5,000 g textiles) Material weight:surface area density: 20 mg/cm^2 (cotton) Surface residue concentration: 0.00024 mg/cm^2 Surface area: 4,130 cm^2 (body minus head and hands) Fraction of body exposed: 0.8 (default skin-contact factor, RIVM 2018) Transfer efficiency: 0.06 (textiles or carpeting, US EPA 2012b) **Post-use oral exposure from wearing clothes** Population: 1 year Exposure (mg/kg bw/day) = surface residue (mg/cm^2) * surface area mouthed (cm^2) * saliva extraction factor / body weight Surface residue: 0.00024 mg/cm^2 Surface area mouthed: 10 cm^2 Saliva extraction factor: 0.48	
Metal polish	Population: adult **Dermal exposure during use** ConsExpo Web (2020) Fact Sheet: Cleaning and washing, miscellaneous cleaning products,	Dermal exposure - applying 13.0 µg/kg bw/day

Scenario	Model and inputs	Exposure
	metal cleaner – naptha based, application – cleaning Model: Dermal, direct product contact – instant application Exposed area: NA Weight fraction: 0.74% Product amount: 1.3 g (default, assumes amount per m^2 applied is equal to the amount per m^2 on the exposed skin)	
Toilet – powder Sentinel scenario covering exposure from tablets	Population: adult **Application rate:** 11.34% boron, 60 mL product **Inhalation exposure while loading powder** Model: PHED M/L wettable powder (no WSP) Unit exposure = 56.2 µg/kg handled (Health Canada 2002a) Concentration of boron: 11.34% Amount handled: 0.104 kg (60 mL product * 1.73 g/cm^3 density)	Inhalation exposure – loading 0.0089 µg/kg bw/day

DIY products

Estimates of exposure to DIY adhesives and sealants, automotive maintenance, home maintenance, and paints and coatings were derived using ConsExpo Web (2020), unit exposure values (Health Canada 2002a, 2020b) and the US EPA Residential SOPs (2011), unless otherwise noted. All estimates were conducted for adults.

Table F-3. DIY: detailed calculations and inputs for estimates of exposure to boric acid as boron equivalents

Scenario	Model and inputs	Exposure
Sealant and caulking	Population: adult ConsExpo Web (2020) Fact Sheet: Do-it-yourself products, sealants, joint sealant, application Model: Dermal, direct product contact – constant rate Constant rate: 50 mg/min Release duration: 30 min Concentration of boron: 1.22%	Dermal exposure 24.8 µg/kg bw/day

Scenario	**Model and inputs**	**Exposure**
Automotive repair paste, filler	Population: adult ConsExpo Web (2020) Fact Sheet: Do-it-yourself products, filler, filler/putty from tube, application Model: dermal, direct product contact – instant application Concentration of boron: 1.64% Product amount: 0.05 g	Dermal exposure 1.1 µg/kg bw/day
Automotive polish Sentinel scenario for automotive polish spray	Population: adult ConsExpo Web (2020) Fact Sheet: cleaning products, floor, carpet and furniture products, floor products, floor polishes, floor polishing liquid, application Model: Dermal, direct product contact – instant application Concentration of boron: 1.29% Product amount: 0.55 g	Dermal exposure 9.6 µg/kg bw/day
Tire mounting paste	Population: adult ConsExpo Web (2020) Fact Sheet: Do-it-yourself products, glues, bottled glue – universal/wood glue, application Model: Dermal, direct product contact – instant application Concentration of boron: 0.113% Product amount: 0.08 g	Dermal exposure 0.12 µg/kg bw/day
Synthetic brake fluid Sentinel scenario covering exposure to antifreeze, engine coolant, radiator flush, radiator sealant repair, radiator cleaner/lubricant	Population: adult Dermal exposure (µg/kg bw/day) = exposed area (cm^2) * thickness of film on skin (cm) × density (g/cm^3) * 1×10^6 (µg/g) * concentration of boron (%) * dermal absorption (fraction) / body weight (kg) Exposed area: 12 cm^2 (based on area of 2 fingertips and 2 thumbs, RIVM 2022) Film thickness: 2×10^{-3} cm (mineral oil, immersion, partial wipe; US EPA 2011) Density: 1.06 g/mL Concentration of boron: 7.00%	Dermal exposure 2.4 µg/kg bw/day
Wood glue	Population: adult ConsExpo Web (2020) Fact Sheet: Do-it-yourself products, glues, universal/wood glue, application	Dermal exposure 0.19 µg/kg bw/day

Scenario	**Model and inputs**	**Exposure**
	Model: Dermal, direct product contact – instant application Concentration of boron: 0.175% Product amount: 0.08 g	
Nail hole filler Sentinel scenario for lubricant and grease pastes	Population: adult ConsExpo Web (2020) Fact Sheet: Do-it-yourself products, filler, filler/putty from tube, application Model: Dermal, direct product contact – instant application Concentration of boron: 1.64% Product amount: 0.05 g	Dermal exposure 1.1 µg/kg bw/day
Wood cleaner, brush	Population: adult ConsExpo Web (2020) Fact Sheet: Painting products, brush and roller painting, water-borne wall paint, application Model: Dermal, direct product contact – constant rate Weight fraction: 0.17% Contact rate: 30 mg/min Release duration: 120 min	Dermal exposure 8.3 µg/kg bw/day
Rust paint, aerosol spray	Population: adult ConsExpo Web (2020) Fact Sheet: Painting products, spray painting, spray can, application **Inhalation exposure during spraying** Model: Inhalation, exposure to spray, spraying Spray duration: 15 min Exposure duration: 20 min Weight fraction: 0.485% Room volume: 34 m^3 Room height: 2.25 m Ventilation rate: 1.5/hr Inhalation rate: 15.1 m^3/day Mass generation rate: 0.45 g/s Airborne fraction: 0.7 Density: 1.5 g/cm^3 Inhalation cut-off diameter: 10 µm (HC refinement)	Inhalation exposure Mean event: 5.6 mg/m^3 Inhalation exposure on day of event: 16.0 µg/kg bw/day Dermal exposure 9.8 µg/kg bw/day

Scenario	Model and inputs	Exposure
	Aerosol diameter: log-normal Median diameter (CV): 15.1 (1.2) µm Maximum diameter: 50 µm **Dermal exposure during spraying** Model: Dermal, direct product contact – constant rate Weight fraction: 0.485% Contact rate: 100 mg/min Release duration: 15 min	
Rust paint, brush	Population: adult ConsExpo Web (2020) Fact Sheet: Painting products, brush and roller painting, water-borne wall paint, application Model: Dermal, direct product contact – constant rate Weight fraction: 0.485% Contact rate: 30 mg/min Release duration: 120 min	Dermal exposure 23.6 µg/kg bw/day
Rust paint, airless sprayer	Population: adult US EPA Residential SOPs (2012b): Treated paints and preservatives, residential handler dermal and inhalation handler exposure algorithm (10.1, 10.2, 10.3) Volume of paint per can: 18 900 mL Density: 1.37 g/mL (product-specific) Weight fraction: 0.485% Unit exposure: dermal 99 297 (single layer, no gloves) µg/kg ai, inhalation 2 169 µg/kg ai (Health Canada 2020b) Number of cans/day: 3	Dermal exposure 50.8 µg/kg bw/day Inhalation exposure 11.1 µg/kg bw/day

Flame retardants

Exposure estimates from flame retardants were derived using the algorithms below unless otherwise noted:

Dermal exposure from sleeping on mattress or futon (µg/kg bw/day) = surface area of skin exposed (cm^2) * migration rate ($µg/cm^2/hr$) * exposure duration (hr/d) * dermal absorption (fraction) / body weight (kg)

Dermal exposure from sleepwear (µg/kg bw/day) = boron concentration (%)/100 * area weight of textile (mg/cm^2) * surface area of skin exposed (cm^2) * % migration /100 * dermal absorption (fraction) / body weight (kg) * conversion from mg to µg

Oral (mouthing) exposure from sleepwear (µg/kg bw/day) = boron concentration (%) /100 * area weight of textile (mg/cm^2) * surface area of textile mouthed (cm^2) * % migration /100 / body weight (kg) * conversion from mg to µg

Table F-4. Flame retardants: detailed calculations and inputs for estimates of exposure to boric acid as boron equivalents

Scenario	Models and inputs	Exposure
Sleeping on mattress or futon	Population: infant 0 to 5 months, adult Surface area of exposed skin: 520, 2,005 cm^{2}[a] Migration rate: 1.12 µg/cm^2/hr[b] Exposure duration: 12.7, 8 hr/d (median sleep time from US EPA 2011, Table 16-25, 26)	Dermal exposure 117.1, 24.2 µg/kg bw/day
Wearing sleepwear	Population: infant 0 to 5 months Boron concentration: 2.21 × 10^{-4}% (maximum measured value, email from Consumer and Hazardous Products Safety Directorate, July 2017) **Dermal from wearing sleepers** Area weight of textile: 20 mg/cm^2 for cotton (US EPA 2012b) Surface area of skin exposed: 2,670 cm^2 (total body minus head and hands) % migration: 15.8%[c] **Oral (mouthing)** Area weight of textile: 20 mg/cm^2 (US EPA 2012b) Surface area of textile mouthed: 10 cm^2 (US EPA 2012b) % migration: 2.3%[d]	Dermal exposure 0.30 µg/kg bw/day Oral (mouthing) exposure 0.0016 µg/kg bw/day

[a] Surface area assumes that the infant is wearing shorts and a T-shirt that cover half of the limbs. The surface area is based on exposure to a fraction of the lower half of the limbs (arms and legs) and of half of the head to represent the back of the head. The surface areas of the limbs were multiplied by one-half to account for clothing coverage and were then multiplied by one-third to account for the triangular shape of limbs, where only one side is directly in contact with the mattress (US CPSC 2006).

[b] The mean migration rate of 6.7 µg/cm^2 over 6 hours was derived from data on the migration of boron from 4 replicates in a study of a full-scale twin mattress (with ticking and a sheet), presented in US CPSC 2006, Table 12b.

[c] An average % migration of boron was derived from 4 data points for cotton-based materials (the % of available FRC extracted from 1 PSI weight perspiration and urine data points for barrier 1 and 11) presented in US CPSC 2005 (Table 4).

[d] An average % migration of boron was derived from 4 data points for cotton-based materials (the % of available FRC extracted from no weight perspiration and urine data points for barrier 1 and 11) presented in US CPSC 2005 (Table 4).

Self-care products (that is, cosmetics, natural health products, and non-prescription drugs)

Exposure estimates were derived using various exposure models and algorithms including ConsExpo Web (2020), the US EPA Residential SOPs (2012b), and other algorithms.

Dermal exposure was typically derived using the following algorithm:

Dermal exposure (µg/kg bw/day) = product amount (g) * 1 × 10^6 µg/g * boron concentration (fraction) * retention factor (fraction) * frequency of use (times/day) * dermal absorption (fraction) / body weight (kg)

The values used for product amount, retention factors, exposure frequency (that is, frequency of use), and retention factors were developed through a process established for CMP assessments (Health Canada 2023b). This process includes a review of the available data on product amount, the frequency of use and retention factors of self-care products for comprehensiveness of the study or survey, the relevance of the data collected, and the type of information collected. The highest central tendency value from the studies with the highest quality rating is selected for use in CMP assessments, and underlying studies are cited. The concentration data were based on information notified to Health Canada under the *Cosmetic Regulations*, from the LNHPD [modified 2023], or from the Natural and Non-prescription Health Products Directorate (personal communication, email from the Natural and Non-prescription Health Products Directorate, Health Canada, to the Existing Substances Risk Assessment Bureau, Health Canada, dated February 5, 2020; unreferenced). A fixed dermal absorption value of 10% was used unless otherwise noted.

Table F-5. Self care products – dermal exposure: detailed calculations and inputs for estimates of exposure to boric acid as boron equivalents

Scenario	Model and inputs	Exposure
Permanent hair colour (cosmetic)	Population: 14 to 18 years, adult Product amount: 30 g (product label) Concentration: 3.97% (30% sodium perborate, 7632-04-4) Retention factor: 0.1	Dermal exposure 191.9, 160.8 µg/kg bw/day
Beard hair conditioner (cosmetic)	Population: 14 to 18 years Product amount: 0.75 g (extrapolated from face lotion, 1/2 product amount, Ficheux et al. 2016; Health Canada 2023b) Concentration: 0.49% (3% sodium borate, 7775-19-1) Retention factor: 1 (leave-in)	Dermal exposure 6.0 µg/kg bw/day
Hair gel	Population: 4 to 8 years	Dermal exposure 6.6 µg/kg bw/day

Scenario	Model and inputs	Exposure
Sentinel scenario covering exposure from hair cream and pomade (cosmetic)	Product amount: 3.1 g (adjusted for child surface area of half of hands and half of head, Ficheux et al. 2016; Health Canada 2023b) Concentration: 0.49% (3% sodium borate, 7775-19-1) Retention factor: 0.1	
Hairspray – aerosol (cosmetic)	Population: 4 to 8 years **Dermal exposure during application** Exposure (µg/kg bw/day) = product amount (g) * 1 × 10^6 µg/g * boron concentration (fraction) * fraction landing on hair * fraction migrating from hair to scalp * dermal absorption fraction * frequency of use (#/day) / body weight (kg) (RIVM 2006) Product amount: 2.3 g (Ficheux et al. 2016; Health Canada 2023b) Concentration: 0.01% (0.1% MEA-borate) Fraction landing on hair: 0.85 (RIVM 2006) Fraction migrating from hair to scalp: 0.1 (RIVM 2006) **Inhalation exposure during application** ConsExpo Web (2020) Fact Sheet: Cosmetics, hair care cosmetics, hairspray, application Model: Inhalation, exposure to spray, spray model Spray duration: 5.75 s (modified 2.3 g used in dermal estimate with a mass generation rate of 0.4 g/s) Exposure duration: 5 min Weight fraction: 0.01% Room volume: 10 m^3 Room height: 2.5 m Ventilation rate: 2/hr Inhalation rate: 11.1 m^3/day Spraying towards person Cloud volume: 0.0625 m^3	Dermal exposure 0.088 µg/kg bw/day Mean event air concentration 0.00055 mg/m^3 Inhalation exposure 0.00092 µg/kg bw/day

Scenario	Model and inputs	Exposure
	Mass generation rate: 0.4 g/s Airborne fraction: 0.15 (adjustment is based on mass balance from dermal estimate of 85% landing on head) Density non-volatile: 1.5 g/cm^3 Inhalation cut-off diameter: 10 µm (refinement) Aerosol diameter distribution type: log-normal Initial droplet distribution – median (C.V.): 46.5 µm (2.1) Maximum diameter: 50 µm	
Body soap, liquid (cosmetic) Sentinel scenario covering exposure from solid body soap (cosmetic), antibacterial hand cleaner (non-prescription drug)	Population: 4 to 8 years Product amount: 10.9 g (Garcia-Hidalgo et al. 2017; Health Canada 2023b) Concentration: 0.49% (3% sodium borate, 7775-19-1) Retention factor: 0.01 Frequency: 1.15 times/day (Ficheux et al. 2015; Health Canada 2023b)	Dermal exposure 2.7 µg/kg bw/day
Baby wash (cosmetic)	Population: 0 to 5 months Product amount: 6.0 g (Gomez-Berrada et al. 2017; Health Canada 2023b) Concentration: 0.016% (0.09% boric acid) Retention factor: 0.01	Dermal exposure 0.16 µg/kg bw/day
Body lotion (cosmetic)	Population: 4 to 8 years, adult Product amount: 5.2, 10 g (Ficheux et al. 2016; Health Canada 2023b) Concentration: 0.49% (3% sodium borate, 7775-19-1) Retention factor: 1	Dermal exposure 111.4, 66.6 µg/kg bw/day
Foot lotion (cosmetic) Sentinel scenario covering exposure from hand cream (cosmetic)	Population: 14 to 18 years Product amount: 4.1 g (Ficheux et al. 2016; Health Canada 2023b) Concentration: 0.05% (0.3% sodium borate, 7775-19-1) Retention factor: 1	Dermal exposure 3.3 µg/kg bw/day
Anti-itch and rash cream (NHP)	Population: 4 to 8 years	Dermal exposure 30.6 µg/kg bw/day

Scenario	Model and inputs	Exposure
	Product amount: 1.25 g (whole body amount adjusted for application to ¼ of body, Ficheux et al. 2016; Health Canada 2023b) Concentration of boron: 0.14% (0.656% sodium tetraborate as non-medicinal ingredient [sodium borate in LNHPD], 1330-43-4) Retention factor: 1 Frequency: 4x/day	
Anti-hemorrhoid cream (NHP)	Population: 4 to 8 years, adults Product amount: 1.7 g (diaper salve; Gomez-Berrada et al. 2013; Health Canada 2023b) Concentration of boron: 0.113% (1% borax as non-medicinal ingredient) Retention factor: 1 (diaper salve) Dermal absorption fraction: 0.5 (to account for potential abrasion and increase in dermal penetration in rectal area) Frequency: 4x/day	Dermal exposure 4 to 8 years 167.6 µg/kg bw/day Adults 52.1 µg/kg bw/day
Massage oil (cosmetic)	Population: 4 to 8 years, adult Product amount: 1.9, 3.2 g (adjusted for total child surface area minus surface area of half head; Ficheux et al. 2016; Health Canada 2023b) Concentration: 0.64% (3% sodium tetraborate) Retention factor: 1	Dermal exposure 53.3, 27.9 µg/kg bw/day
Hair removal after-care (cosmetic)	Population: 9 to 13 years, adult Product amount: 5.5, 7.1 g (adjusted for youth surface area, half of total surface area; Ficheux et al. 2016; Health Canada 2023b) Concentration: 0.052% (0.3% boric acid) Retention factor: 1 Dermal absorption fraction: 0.5 (to account for potential increase in dermal penetration following hair removal)	Dermal exposure 34.3, 25.2 µg/kg bw/day
Face exfoliant (cosmetic)	Population: 14 to 18 years Product amount: 3.1 g (Ficheux et al. 2016; Health Canada 2023b)	Dermal exposure 2.2 µg/kg bw/day

Scenario	Model and inputs	Exposure
Sentinel scenario covering exposure from face cleanser (cosmetic) and acne face wipes (NHP)	Concentration: 2.55% (3% borax pentahydrate) Retention factor: 0.1	
Face makeup removal lotion (cosmetic) Sentinel scenario covering exposure from face makeup liquid, eye makeup removal lotion (cosmetic)	Population: 4 to 8 years old Product amount: 2.2 g (Ficheux et al. 2016; Health Canada 2023b) Concentration: 0.87% (5% boric acid) Retention factor: 0.1	Dermal exposure 8.4 µg/kg bw/day
Face mask (cosmetic)	Population: 14 to 18 years Product amount: 9.7 g (Ficheux et al. 2016; Health Canada 2023b) Concentration: 0.03% (0.1% sodium borohydride) Retention factor: 0.1	Dermal exposure 0.45 µg/kg bw/day
Face lotion (cosmetic)	Population: adults Product amount: 1.5 g (Ficheux et al. 2016; Health Canada 2023b) Concentration: 0.49% (3% sodium borate, 7775-19-1) Retention factor: 1 Frequency: 2x/day (Loretz et al. 2005; Health Canada 2023b)	Dermal exposure 35.4 µg/kg bw/day
Eyebrow tint (cosmetic) Sentinel scenario covering exposure from eyelash adhesive	Population: 14 to 18 years Product amount: 0.175 g (product label) Concentration: 1.32% (10% sodium perborate, 7632-04-4) Retention factor: 0.1 (product label)	Dermal exposure 0.37 µg/kg bw/day
Eyeshadow cream (cosmetic) Sentinel scenario covering exposure from mascara, eyeshadow powder, eyelash	Population: 4 to 8 years Product amount: 0.009 g (RIVM 2006; Health Canada 2023b) Concentration of boron: 0.093% (0.3% boron oxide) Retention factor: 1	Dermal exposure 0.037 µg/kg bw/day

Scenario	Model and inputs	Exposure
serum and eyebrow serum.		
Nail adhesive (cosmetic)	Population: 14 to 18 years Product amount: 0.04 g (base coat; Ficheux et al. 2014; Health Canada 2023b) Concentration: 0.076% (1% boron trifluoride monoetherate) Retention factor: 1	Dermal exposure 0.049 µg/kg bw/day
Nail adhesive (cosmetic) Sentinel scenario covering inhalation exposure from eyelash adhesive	Inhalation exposure to boron trifluoride monoetherate ConsExpo Web (2020) Fact Sheet: Cosmetics, makeup cosmetics, nail polish, application Model: Inhalation, exposure to vapour, evaporation Exposure duration: 5 min Molecular weight matrix: 124 g/mol Product amount: 0.04 g (base coat; Ficheux et al. 2014; Health Canada 2023b) Weight fraction: 1% boron trifluoride monoetherate Room volume: 1 m^3 Ventilation rate: 2/hr (bathroom) Vapour pressure: 5×10^{-6} Pa Application temperature: 20ºC Molecular weight: 142 g/mol Mass transfer coefficient: 10 m/hr Release area mode: constant Emission duration: 5 min	Mean event concentration 0.42 mg boron trifluoride monoetherate/m^3 4 hour TWA 0.0088 mg boron trifluoride monoetherate/m^3
Bath bomb (cosmetic) Sentinel scenario covering exposure from bath salts (cosmetic)	Population: 4 to 8 years **Dermal exposure during use** Exposure (µg/kg bw/day) = Exposure time (hr/day) * surface area (cm^2) * permeability co-efficient (cm/hr) * boron concentration (fraction) * [product amount (g) * 1,000 mg/g / volume bathtub (L)] * (0.001 L/cm^3) * (1000 µg/mg) / body weight (kg)	Dermal exposure 0.78 µg/kg bw/day

Scenario	Model and inputs	Exposure
	Exposure time: 0.4 hr/day, time spent bathing (US EPA 2011) Surface area: 8,290 cm^2 (total body minus head) Permeability co-efficient (K_P): 0.0005 cm/hr (Wester et al. 1998b) Concentration: 0.65% (3% sodium tetraborate) Product amount: 200 g (large bath bomb, professional judgment) Volume of bathtub: 120 L (RIVM 2006)	

Self-care products: oral, ocular, and otic exposure

Oral, ocular, and otic exposure estimates from self-care products were derived using the algorithms below unless otherwise noted:

Oral exposure (µg/kg bw/day) = product amount * boron concentration * frequency of use (times/day) * [unit conversion if needed] / body weight (kg)

Oral exposure (µg/kg bw/day) = boron amount * frequency of use (times/day) * [unit conversion if needed] / body weight (kg)

Ocular and otic exposure (µg/kg bw/day) = dose volume (or volume available for absorption) (mL/use) * boron concentration * frequency of use (use/day) * [density 1 g/mL if needed and/or unit conversion factor if needed] * [dermal absorption for otic] / body weight (kg)

Table F-6. Self care products – products with oral, ocular, and otic exposure: detailed calculations and inputs for estimates of exposure to boric acid as boron equivalents

Scenario	Model and inputs	Exposure
Multi-vitamin/mineral and workout supplements (NHP)	Population: adult **Oral exposure from use** Exposure (µg/kg bw/day) = boron amount (µg/d) / body weight (kg) Boron amount: 700 µg/day (as medicinal ingredient; Health Canada 2022c, 2023c).	Oral exposure 9.5 µg/kg bw/day
Children's multi-vitamin/mineral supplements (NHP)	Population: 6 to 8 years **Oral exposure from use**	Oral exposure 7.26 µg/kg bw/day

Scenario	Model and inputs	Exposure
	Exposure (µg/kg bw/day) = boron amount (µg/d) / body weight (kg). Boron amount: 0.167 mg (as medicinal ingredient from boric acid or boron HVP chelate) Frequency: 1 per day	
Joint health products (NHP)	Population: adult Boron amount: 3.36 mg/day (as medicinal ingredient; Health Canada 2022b)	Oral exposure 45.4 µg/kg bw/day
Other oral supplements (NHP)	Population: adult Boron amount: 5 mg (as medicinal ingredient from borax) Frequency: 2x/day	Oral exposure 135.1 µg/kg bw/day
Tooth whitener (cosmetic)	Population: adult Product amount: 0.08 g (toothpaste, SCCS 2015; Ficheux et al. 2016; Health Canada 2023b) Concentration: 0.311% (1% boron oxide)	Oral exposure 3.4 µg/kg bw/day
Toothpaste (cosmetic) Sentinel scenario covering exposure from toothpaste (NHP)	Population: 9 to 13 years old Product amount: 0.14 g (Strittholt et al. 2016; Health Canada 2023b) Concentration: 0.04% (0.3% sodium perborate, 7775-19-1) Frequency: 2.6x/day (Ficheux et al. 2015; Health Canada 2023b)	Oral exposure 3.4 µg/kg bw/day
Mouthwash (cosmetic) Sentinel scenario covering exposure from mouth appliance and denture cleaner (cosmetic)	Population: 4 to 8 years, adult Product amount: 1, 1.7 g (product label, SCCS 2015; Health Canada 2023b) Concentration: 0.04% (0.3% sodium perborate)	Oral exposure 17.2, 9.1 µg/kg bw/day
Lip products with SPF (non-prescription drug) Sentinel scenario covering exposure to lip moisturizer products (cosmetic)	Population: 4 to 8 years Product amount: 0.022 g (Ficheux et al. 2016; Health Canada 2023b) Concentration of boron: 0.29% (1.36% sodium borate, 7775-19-1) Frequency: 1.2x/day (Statistics Canada 2017; Health Canada 2023b)	Oral exposure 3.4 µg/kg bw/day
Eye drops (NHP) Acute use	Population: adult	Ocular exposure 8.1 µg/kg bw/day

Scenario	Model and inputs	Exposure
Sentinel scenario covering acute exposure from non-prescription drug eye drop products	Dose volume: 0.04 mL (Commercial eye droppers deliver drop sizes ranging from 25 to 50 µL; however, the conjunctival sac in adults can hold only 10 µL. Assume that the volume of the conjunctival sac is available for absorption and that the remainder will overflow [Farkouh et al. 2016 as cited in ECCC, HC 2019]. Dose volume of 10 µL * 4 drops (2 drops/eye, 2 eyes) (LNHPD) Concentration of boron: 0.187% (1.067% boric acid as non-medicinal ingredient) Frequency: 8x/day for acute or short-term use (product-specific)	
Eye drops (non-prescription drug) Chronic use Sentinel scenario covering chronic exposure from NHP eye drop products	Population: 4 to 8 years, adult Dose volume: 0.0292, 0.04 mL (Commercial eye droppers deliver drop sizes ranging from 25 to 50 µL; however, the conjunctival sac in adults can hold only 10 µL. Assume that the volume of the conjunctival sac is available for absorption and that the remainder will overflow [Farkouh et al. 2016 as cited in ECCC, HC 2019]. Child dose volume adjusted for conjunctival sac capacity of 7.3 µL for 5-year-old scaled from 10 µL for adult based on eyeball weight ratio adult:5-year-old of 15 g:11 g [ICRP 1975]) * 4 drops (2 drops/eye, 2 eyes) Concentration of boron: 2.69 mg/mL (15.4 mg/mL boric acid) Frequency: 3x/day for chronic use (product-specific)	Ocular exposure 10.3, 4.4 µg/kg bw/day
Contact lens solution (non-prescription drug)	Population: 9 to 13 years **Ocular exposure during application** Volume available for absorption: 0.0172 mL (based on conjunctival	Ocular exposure 0.43 µg/kg bw/day Dermal exposure 0.82 µg/kg bw/day

Scenario	Model and inputs	Exposure
	sac capacity of 10 μL for adult [Farkouh et al. 2016 as cited in ECCC, HC 2019] scaled to 8.6 μL/eye from eyeball weight ratio of adult:10-year-old of 15 g:12.9 g [ICRP 1975]) * 2 eyes Concentration of boron: 1.05 mg/mL (6 mg boric acid/mL) (DPD [modified 2023]) **Dermal exposure on hands during use** Exposure (μg/kg bw/day) = exposed area (cm^2) × thickness of film on skin (cm) × concentration of boron (mg/ml) * 1,000 μg/mg * dermal absorption (fraction) / body weight (kg) Exposed area: 152 cm^2 (one palm from surface area of both hands/4, Health Canada [modified 2022b]) Thickness of film: 2.14×10^{-3} cm (water, immersion, partial wipe; US EPA 2011) Concentration of boron: 1.05 mg/mL (6 mg boric acid/mL) (DPD [modified 2023])	
Eye wash (NHP)	Population: 4 to 8 years Concentration of boron: 0.245% (1.4% boric acid as non-medicinal ingredient) **Ocular exposure during application** Volume available for absorption: 0.0146 mL (based on conjunctival sac capacity of 10 μL for adult [Farkouh et al. 2016 as cited in ECCC, HC 2019] scaled to 7.3 μL from eyeball weight ratio of adult:5-year-old of 15 g:11 g [ICRP 1975] * 2 eyes) **Dermal exposure during use**	Ocular exposure 1.6 μg/kg bw/day Dermal exposure 2.1 μg/kg bw/day

Scenario	Model and inputs	Exposure
	Exposure (µg/kg bw/day) = volume product (mL) * density (1g/mL) * boron concentration (%/100) * retention factor * dermal absorption (fraction) * conversion µg/g / body weight (kg) Volume: 19.98 mL (total volume of product used, 20 mL, corrected for volume available for ocular exposure, 0.0146 mL) Retention factor: 0.01 (face wash)	
Ear drops (non-prescription drug)	Population: 0 to 5 months **Otic exposure during use** Dose volume: 0.15 mL (50 µL/drop, assuming same size as eye drops [Farkouh et al. 2016 as cited in ECCC, HC 2019] * 3 drops in affected ear, product label) Concentration of boron: 1.74 mg/mL (10 mg boric acid/mL, DPD [modified 2023]) Frequency: 4x/day (product label, DPD [modified 2023]) Dermal absorption: 0.1	Dermal exposure 16.7 µg/kg bw/day

Swimming pool and spa maintenance products

Exposure estimates for swimming pool and spa maintenance products were derived used PHED unit exposures (Health Canada 2002a) and the US EPA SWIMODEL (2003, 2016).

Table F-7. Swimming pool and spa maintenance products: detailed calculations and inputs for estimates of exposure to boric acid as boron equivalents

Scenario	Model and inputs	Exposure
Application of product to pool – powder	Population: adult **Application rate:** 70 ppm (0.70 kg per 10 000 L), recommended concentration in saltwater pools **Inhalation exposure while pouring**	Inhalation exposure 4.0, 0.16 µg/kg bw/day

Scenario	Model and inputs	Exposure
	Model: PHED Inhalation, open, mixing and loading, wettable powder (no WSP) and granules Unit exposure = 56.2 µg/kg handled for wettable powder, 2.2 µg/kg handled for granules (Health Canada 2002a) Amount of boron handled: 5.3 kg/day (70 ppm = 0.7 kg per 10 000 L, typical residential pool 75 600 L, default US EPA 2015b)	
Swimming in pool Sentinel scenario covering exposure from spa use	Population: 4 to 8 years, adult **US EPA SWIMODEL** (US EPA 2003, 2016) Kp (boric acid): 5.0×10^{-4} cm/hr (Wester et al. 1998b) Boron concentration: 70 mg/L (in saltwater pool) Skin surface area: 8 900, 18 700 cm^2, whole body Exposure time: 2.7 hr/day (Health Canada 2022a), 1 hr/day (US EPA 2003, 2016) Ingestion rate: 0.038 L/hr (Health Canada 2022a), 0.025 L/hr (US EPA 2003, 2016)	Dermal exposure 36.6, 8.8 µg/kg bw/day Oral exposure 312.3, 23.7 µg/kg bw/day

Appendix G. Biomonitoring data tables

Table G-1. Concentrations of total boron in urine (µg/g creatinine) in Canada

Study population	Age, years	Sex	n	Median (95% CI)	95th percentile (95% CI)	Reference
CHMS 2016 to 2017	3 to 79	M+F	2691	880 (800 to 960)	2,900 (2600 to 3,300)	Health Canada 2023d
CHMS, 2018 to 2019	3 to 79	M+F	2533	990 (900 to 1,100)	2,900 (2,600 to 3,300)	Health Canada 2023d
CHMS, 2018 to 2019	3 to 79	M	1255	950 (830 to 1,100)	2,700 (2100 to 3,300)	Health Canada 2023d

CHMS, 2018 to 2019	3 to 79	F	1278	1,000 (850 to 1,200)	3,200 (2,700 to 3,700)	Health Canada 2023d
CHMS, 2018 to 2019	3 to 5	M+F	515	2,500 (2,300 to 2,600)	5,800 (4,800 to 6,700)	Health Canada 2023d
CHMS, 2018 to 2019	3 to 5	M	253	2,500 (2,300 to 2,700)	5,500 (4,400 to 6,500)	Health Canada 2021
CHMS, 2018 to 2019	3 to 5	F	262	2,600 (2,300 to 2,900)	6,400 (5,200 to 7,500)	Health Canada 2021
CHMS, 2018 to 2019	6 to 11	M+F	499	1,300 (1,100 to 1,400)	3,200 (2,900 to 3,600)	Health Canada 2023d
CHMS, 2018 to 2019	6 to 11	M	249	1,400 (1100 to 1,700)	3,300 (2,900 to 3,700)	Health Canada 2021
CHMS, 2018 to 2019	6 to 11	F	250	1,300 (1,100 to 1,500)	3,000 (2,600 to 3,300)	Health Canada 2021
CHMS, 2018 to 2019	12 to 19	M+F	505	690 (620 to 760)	1,900(1,300 to -2,600)	Health Canada 2023d
CHMS, 2018 to 2019	12 to 19	M	251	600 (480 to 730)	1,700 (1,300 to 2,100)	Health Canada 2021
CHMS, 2018 to 2019	12 to 19	F	254	780 (680 to 880)	2,200 (680 to 3,600)	Health Canada 2021
CHMS, 2018 to 2019	20 to 39	M+F	329	810 (670 to 950)	2,300 (1,900 to 2,700)	Health Canada 2023d
CHMS, 2018 to 2019	20 to 39	M	164	810 (610 to 1,000)	2,100 (1,700 to 2,500)	Health Canada 2021
CHMS, 2018 to 2019	20 to 39	F	165	840 (670 to 1,000)	2,600 (2,000 to 3,100)	Health Canada 2021
CHMS, 2018 to 2019	40 to 59	M+F	342	1,000 (800 to 1,200)	3,100 (2,300 to 4,000)	Health Canada 2023d
CHMS, 2018 to 2019	40 to 59	M	171	950 (760 to 1,100)	2,500 (1,700 to 3,200)	Health Canada 2021

CHMS, 2018 to 2019	40 to 59	F	171	1,200 (910 to 1,500)	3,400 (3,000 to 3,800)	Health Canada 2021
CHMS, 2018 to 2019	60 to 79	M+F	343	1,000 (810 to 1,300)	2,900 (2,300 to 3,500)	Health Canada 2023d
CHMS, 2018 to 2019	60 to 79	M	167	1,000 (810 to 1,200)	2,500 (1,600 to 3,400)	Health Canada 2021
CHMS, 2018 to 2019	60 to 79	F	175	1,300 (1,000 to 1,600)	3,500 (2,800 to 4,300)	Health Canada 2021
JES!–YEH! First Nations Youth, 2015	3 to 19	M+F	50	991 (798 to 1,254)	4,387	Lemire et al. 2019[b]
JES!–YEH! First Nations Youth, 2015	3 to 19	M	26	882[a] (702 to 1,186)	3,817	Lemire et al. 2019[b]
JES!–YEH! First Nations Youth, 2015	3 to 19	F	24	991[a] (734 to 1,856)	4,194	Lemire et al. 2019[b]
JES!–YEH! First Nations Youth, 2015	3 to 5	M+F	10	2,549[a] (1,131 to 3,264)	6,986	Lemire et al. 2019[b]
JES!–YEH! First Nations Youth, 2015	6 to 11	M+F	19	1,253 (991 to 1,474)	4,364	Lemire et al. 2019[b]
JES!–YEH! First Nations Youth, 2015	12 to 19	M+F	21	615 (406 to 702)	951	Lemire et al. 2019[b]
JES!–YEH! Anishinaabe 2015	3 to 19	M+F	28	1,103 (837 to 1,505[a])	4,423	Lemire et al. 2019[b]
JES!–YEH! Innu, 2015	3 to 19	M+F	22	819 (434 to 1,146[a])	2,836	Lemire et al. 2019[b]

Abbreviations: CI, confidence interval; M, male; F, female

[a] Use data with caution (CV is between 16.6% and 33.3% and has high sampling variability).

[b] Adjusted to µg/g creatinine from µmol/g creatinine, as reported in Lemire et al. (2019), using the molecular weight of boron of 10.811.

Table G-2. Concentrations of total boron concentrations in blood (µg/L) in the general population

Population and sample type	Age group	Sex	n	Mean ± SD µg/L	Maximum µg/L	Reference
Alberta, pregnant women, serum	under 25 to 31+	F	151 pools	13 to 34	N/A	Alberta Health and Wellness 2008
Alberta, children, serum	2 to 13	M+F	6 pools	29 to 33	N/A	Government of Alberta 2010
Northern SK, pregnant women, serum	NA	F	6 pools n=841	17 overall, 13 to 24	N/A	Government of Saskatchewan, 2019
UK, whole blood	NA	NA	50	56.7	170.4	Abou-Shakra et al. 1989
UK, serum	NA	NA	50	22.3	48.1	Abou-Shakra et al. 1989
Northern Germany, whole blood	18 to 70	M+F	130	42	195	Heitland and Köster 2006
Northern France, plasma	21.2 (mean)	M	180	126.11 ± 106.27	600	Yazbeck et al. 2005
France, whole blood	NA	NA	100	Median 26	44 (P95)	Goullé et al. 2005
France, plasma	NA	NA	100	Median 36	79 (P95)	Goullé et al. 2005

Abbreviations: SD, standard deviation; NA, not available; N/A, not applicable
Assumed blood density was 1g/mL when converting weight/weight (wt/wt) to weight/volume (wt/vol).

Appendix H. Reverse dosimetry models for biomonitoring data

Urine model

The estimated daily intakes for boron were calculated from CHMS biomonitoring data using a mass balance approach. The mass balance approach relies on the urinary excretion fraction (F_{UE}) for the substance and standard urine creatinine excretion rates (Aylward et al. 2015). An average F_{UE} of 0.89 was derived on the basis of studies in humans (Kent and McCance 1941; Jansen et al. 1984a; Schou et al. 1984; Hunt et al. 1997; Naghii and Samman 1997; Samman et al. 1998; Sutherland et al. 1998). Average urine creatinine excretion rates (in g creatinine/kg bw/day) for different age groups were obtained from Aylward et al. (2015).

$$\mathbf{BDI = B_{urine} \times CE_{24} / F_{UE}}$$

BDI = boron daily intake (µg/kg bw/day)
B_{urine}= boron urine concentration (µg/g creatinine)
CE_{24} = 24-hour creatinine excretion rate (g creatinine/kg bw/day)
F_{UE} = urinary excretion fraction

Table H-1. Median and P95 daily intake of boron based on CHMS Cycle 6 biomonitoring data (2018–2019)

Study	Age group (years)	Sex	CE_{24} (g creatinine/kg bw/day)[a]	Median B_{urine} (µg/g creatinine)[b]	P95 B_{urine} (µg/g creatinine)[b]	Median BDI (µg/kg bw/day)[c]	P95 BDI (µg/kg bw/day)[c]
CHMS	3 to 79	M+F	0.019	990	2900	21.1	61.9
CHMS	3 to 79	M	0.019	950	2700	20.3	57.6
CHMS	3 to 79	F	0.019	1000	3200	21.3	68.3
CHMS	3 to 5	M+F	0.016	2500	5800	44.9	104.3
CHMS	6 to 11	M+F	0.019	1300	3200	27.8	68.3
CHMS	12 to 19	M+F	0.021	690	1900	16.3	44.8
CHMS	20 to 39	M+F	0.020	810	2300	18.2	51.7
CHMS	40 to 59	M+F	0.020	1000	3100	22.5	69.7
CHMS	60 to 79	M+F	0.020	1000	2900	22.5	65.2
CHMS	3 to 5	M	0.016	2500	5500	44.9	98.9
CHMS	3 to 5	F	0.016	2600	6400	46.7	115.1
CHMS	20 to 39	F	0.020	840	2600	18.9	58.4

Abbreviations: M, male; F, female; CE_{24}, 24-hour creatinine excretion rate; B_{urine}, boron urine concentration; P95, 95th percentile; BDI, boron daily intake; NA, not available
[a] Aylward et al. 2015
[b] Health Canada 2021, 2023d
[c] Estimated using the mass balance equation: BDI = $B_{urine} \times CE_{24} / F_{UE}$, where: F_{UE} = urinary excretion fraction (0.89).

Boron blood model

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). A three-compartment model used to describe blood and urine concentrations 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 3 days of intake (Jansen et al. 1984a, 1984b). This model may also suggest that accumulation of boron depends on the rate of depletion of 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 by Dourson et al. (1998), the consistency for mean blood boron concentrations and exposure doses was within the expected variability for most pharmacokinetic data (WHO 2010). 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 (that is, through diet, supplements, or drinking water) were selected when deriving the regression correlation because these sources of exposure are more relevant for the general population (see Appendix G). In supplementation studies, individuals were supplemented with known concentrations of boron, and blood boron concentrations were monitored at regular intervals (Green and Ferrando 1994; Hunt et al. 1997; Nielsen and Penland 1999; Wallace et al. 2002). Intake estimates from supplementation studies include boron exposure from both supplemental and dietary sources. Because boron is well absorbed and is excreted in urine, Nielson and Penland (1999) estimated boron intakes on the basis of urinary boron excretion. In Hunt et al. (1997), the blood boron concentration was presented as µmoles per litre, with the molecular weight of 10.8 g/mol applied to calculate the blood boron concentration in µg/L. In Green and Ferrando (1994), the average plasma boron concentrations were calculated on the basis of the individual plasma data. For individuals with plasma boron concentrations below or equal to the limits of detection, half of the limit was assumed in subsequent analyses.

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 using boron concentrations in drinking water; 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). Similarly to Barr et al (1993), Harari et al. (2012) did not include a dietary component in the derivation of 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 exposure estimates for 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 the boron workers, but without workplace boron exposure, whereas 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/day. Where 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, the body weights of Chinese people are lower than the other ethnic groups; therefore, an average body weight of 60 kg was applied. When the blood boron concentrations were presented on a (wt/wt) basis, the blood density was assumed to be 1 g/mL in order to convert blood boron concentrations from wt/wt to wt/v.

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

Blood concentration (µg/L) = 1,008.8 (daily intake)$^{0.7339}$
where daily intake is in mg B/kg bw/day.

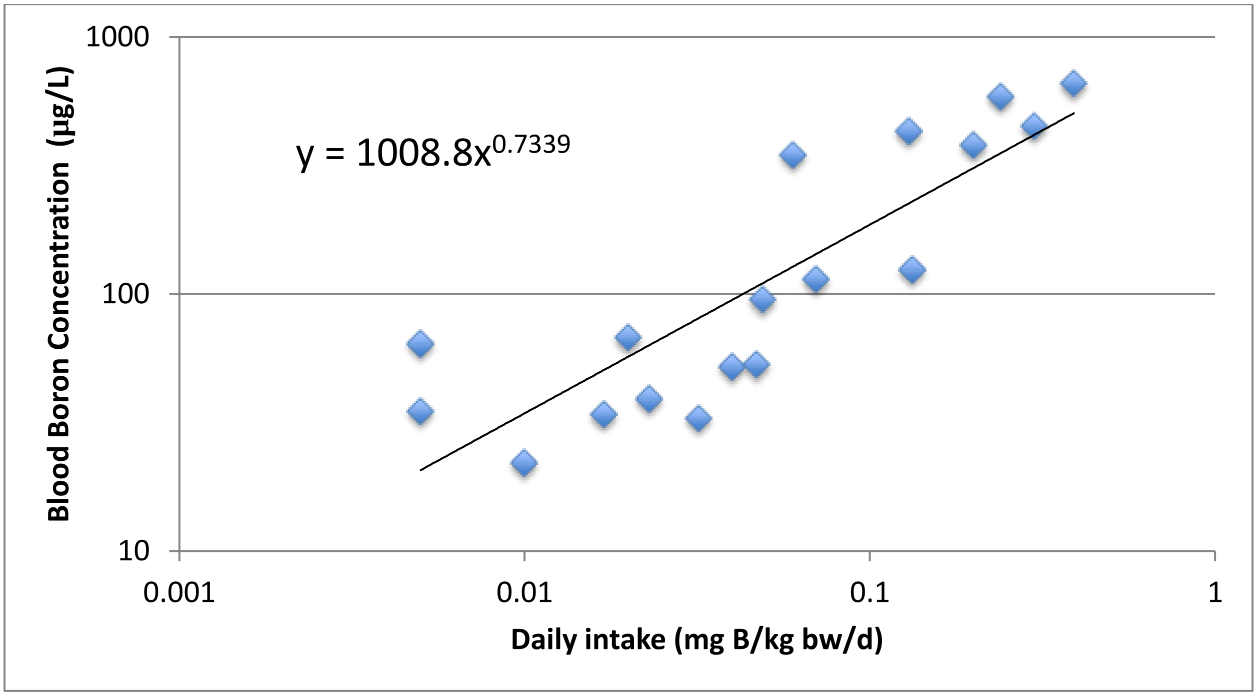

Figure H-1. Blood boron concentrations as a function of daily intakes based on several exposure studies

[Figure H-1 Graph shows the regression correlation using power function for boron daily intake and blood boron concentration. The graph is plotted using logarithmic scale with a base of 10. The daily intake is in units milligrams of boron per kilogram body weight per day and the blood concentrations in microgram per liter. Individual data points from studies where the primary exposure source was from supplements, drinking water and control groups from occupational studies -, are plotted along with a line of best fit. The mathematical equation for the correlation is boron blood concentration equals 1,008.8 times daily intake to the power of 0.7339.]

Table H-2. Summary of blood boron concentrations and intake concentrations in various human exposure studies

Exposure type	Mean intake (mg B/kg bw/day)	Mean blood concentration ± SD or (min-max) (µg/L)	Biological medium	Reference
Supplement study (placebo)	0.017[ac]	34 ± 10	plasma	Nielsen and Penland 1999
Supplement	0.047[ac]	53 ± 12	plasma	Nielsen and Penland 1999
Supplement study (placebo)	0.005[c]	64 ± 45[e]	plasma	Hunt et al. 1997
Supplement	0.049[c]	95 ± 56[e]	plasma	Hunt et al. 1997
Supplement	0.032[c]	32.9 (≤ to 12–77)[f]	plasma	Green and Ferrando 1994
Supplement	0.133[c]	124 ± 20[g]	plasma	Wallace et al. 2002
Drinking water (northern Chile)	0.010[a]	22 ± 2[g]	whole blood	Barr et al. 1993
Drinking water	0.020[a]	68 ± 34[g]	whole blood	Barr et al. 1993
Drinking water	0.040[a]	52 ± 15[g]	whole blood	Barr et al. 1993
Drinking water	0.06[a]	347 ± 163[g]	whole blood	Barr et al. 1993
Drinking water	0.24[a]	585 ± 166[g]	whole blood	Barr et al. 1993
Drinking water	0.300[a]	450 ± 87[g]	whole blood	Barr et al. 1993
Drinking water	0.39[a]	659 ± 337[g]	whole blood	Barr et al. 1993
Drinking water, mother-infant (Argentina)	0.13[ad]	GM 430 (210–1,500)	plasma	Harari et al. 2012
Drinking water, mother-infant (Arica, northern Chile)	0.20[ad]	GM 380 (125–1,360)	whole blood	Harari et al. 2012
Drinking water, mother-infant (Santiago, Chile)	0.005[ad]	GM 35 (21–66)	plasma	Harari et al. 2012
Worker study, China (remote control)	0.02[bh]	39.1 (8.20–72.1)	serum	Scialli et al. 2010
Worker study, China (2004 community control)	0.07[bh]	114 (3.29–348)	serum	Scialli et al. 2010

[a] Assumed to weigh 70 kg

[b] Assumed to weigh 60 kg because the average body weight of Chinese cohorts is lower than the other cohorts.

[c] Intake estimates include dietary intakes

[d] Assumed water consumption of 1.8L/day (as per Barr et al. 1993)

[e] Data presented in µmol/L: molecular weight of boron of 10.8 g/mol was used to convert µg/L.
[f] Average was calculated using individual plasma boron concentrations; half of the detection limit was assumed for data at ≤ limit of detection.
[g] Blood density of 1 kg/L was assumed when converting weight/weight to weight/volume.
[h] Boron exposure through environmental media (mainly diet and drinking water)

Table H-3. Predicted systemic daily exposure (µg/kg bw/day) to boric acid from blood biomonitoring data (µg/L)

Data set	Sex	Age	Median biomonitoring concentration (µg/g creatinine or µg/L)	P95 biomonitoring concentration (µg/g creatinine or µg/L)	Median exposure[a] (µg/kg bw/day)	P95 exposure (µg/kg bw/day)
Alberta	pregnant F	adult	blood 34	N/A	9.9	N/A
Alberta	M + F	2 to 13	blood 33	N/A	9.5	N/A
Northern Saskatchewan	pregnant F	adult	blood 24	N/A	6.1	N/A

[a] Predicted using the equation blood concentration (µg/L) = 1,008.8 (daily intake)$^{0.7339}$ where daily intake is in mg B/kg bw/day