Binational Strategy for Hexabromocyclododecane (HBCD) Risk Management

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A document to assist in the engagement of key stakeholders and the public in strategy development

Prepared by the Governments of the United States and Canada

Disclaimer

The purpose of this document is to propose hexabromocyclododecane (HBCD) risk mitigation and management strategies in accordance with Annex 3 of the Great Lakes Water Quality Agreement (GLWQA). The mention of trade names, commercial products, or organizations does not imply endorsement by the Canadian or United States governments.

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Executive Summary

The Canada-United States Great Lakes Water Quality Agreement (GLWQA) seeks to reduce the anthropogenic release of chemicals of mutual concern (CMCs), including hexabromocyclododecane (HBCD), into the air, water, land, sediment, and biota that may impair the quality of the Waters of the Great Lakes. Under the GLWQA the Parties have agreed to adopt, as appropriate, the principles of virtual elimination and zero discharge for releases and control of CMCs.

This document provides a Binational Strategy for HBCD to focus the efforts of the Governments of Canada and the United States, in cooperation and consultation with State and Provincial Governments, Tribal Governments, First Nations, Métis, Municipal Governments, watershed management agencies, other local public agencies, industry, and the public in implementing risk mitigation and management options aimed at reducing HBCD in the Great Lakes region. The Parties and their partners will use this strategy as guidance to identify, prioritize, and implement actions to reduce CMCs. Strategy options are organized under five categories: Regulations and Other Risk Mitigation and Management Actions; Compliance Promotion and Enforcement; Pollution Prevention; Monitoring, Surveillance, and Other Research Efforts; and Domestic Water Quality. The Parties commit to incorporating, to the extent feasible, options outlined herein in their decisions on programs, funding, and staffing, but implementation would take place by agencies with mandates to undertake work in these areas. As noted in the GLWQA, the Parties' obligations are subject to the appropriation of funds in accordance with their respective procedures.

HBCD is a manmade brominated flame retardant that was primarily used as an additive to expanded polystyrene (EPS) and extruded polystyrene (XPS) foam boards for residential and commercial structures. The increased availability of alternative flame retardants has resulted in a significant decline in HBCD foam board use in the United States and Canada. However, due to the high stability of the compound, HBCD can be found in sediments, waters, biota tissues, wastes, and air in the region. HBCD has also been found to have persistent, bioaccumulative, and toxic (PBT) characteristics.

Formal federal risk mitigation measures and management activities are under way within the United States and Canada. In June 2017, the US Environmental Protection Agency (US EPA) published the scope of the risk evaluation to be conducted as per the *Toxic Substances Control Act*. In Canada, the manufacture, import, use and sale of HBCD and certain products containing it are prohibited under the *Prohibition of Certain Toxic Substances Regulations* as of January 1, 2017.

A clear understanding of the overall status of HBCD within the Great Lakes is lacking due to the sparsity of information and data, including environmental concentrations and estimates of usage in consumer goods and products. While general surveillance data indicate the presence of HBCD in multiple media throughout the region, the available environmental data are too limited to determine whether concentrations exceed environmental quality guidelines and/or benchmarks (ITT, 2015). Research is needed to improve analytical methods in a variety of environmental media to ensure consistent, standardized, and cost-effective binational environmental monitoring of HBCD. Additional work is also needed to assess HBCD alternatives for environmental risks. To address these gaps, this Binational Strategy document proposes multiple options as outlined in **ES Table A**. By implementing these options, stakeholders will be improving the health of the Great Lakes Basin and their respective communities.

ES Table A. Summary of the Canada-United States Strategy Options for HBCD

Category of Action				
Regulations and Other Risk Mitigation and Management Actions	**Compliance Promotion and Enforcement**	**Pollution Prevention**	**Monitoring, Surveillance, and Other Research Efforts**	**Domestic Water Quality**
Strategy Options				
Generate phase-out deadlines for HBCD usage at the federal level (US) Establish environmental and drinking water standards at the federal level (US) Evaluate alternatives to HBCD (US) Quantify releases of HBCD from various products during their life-cycle (production, use, storage, and disposal) (Canada and US)	Promote compliance with *the Prohibition of Certain Toxic Substances Regulations, 2012* (Canada) Promote compliance with toxics release inventory (TRI) database reporting (US) Identify and establish safe disposal methods for HBCD-containing products (US) Promote safe disposal of HBCD-containing products (Canada and US)	Increase public outreach and educate the public and facility staff on potential sources of HBCD and proper actions to follow should HBCD-containing materials be found (US) Educate the public on less toxic alternative flame retardants (US) Encourage industries to use P2 activities and track their efforts in the TRI database (US) Highlight and share P2 successes (US) Support stakeholders that are seeking alternatives to brominated flame retardants, including HBCD (Canada and US)	Monitor HBCD in Great Lakes environmental media (air, sediment, waters, fish, and other wildlife) and publish results in a variety of publications to maximize the intended audience (Canada and US) Develop models to track long-range atmospheric HBCD transport and deposition into the Great Lakes Basin and degradation pathways of various HBCD stereoisomers found within the Great Lakes Basin (US) Use monitoring and modeling to better characterize HBCD sources as a basis for potential actions, measuring progress, and formulating an international decision-making framework (Canada and US) Develop cost-effective tools for monitoring HBCD concentrations from various sources (Canada and US) Develop structured data systems and plans for HBCD source, manifest, and product tracking (US)	Develop and implement appropriate domestic water quality standards for drinking water and surface waters (US)

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Acronyms and Abbreviations

AOC	Areas of Concern
CEPA	Canadian Environmental Protection Act, 1999
CMC	Chemicals of Mutual Concern
CSMI	Cooperative Science and Monitoring Initiative
EB	Executive Body
ECCC	Environment and Climate Change Canada
EPS	Expanded Polystyrene
FEQG	Federal Environmental Quality Guideline
GLENDA	Great Lakes Environmental Database
GLLA	Great Lakes Legacy Act
GLNPO	Great Lakes National Program Office
GLRI	Great Lakes Restoration Initiative
GLWQA	Great Lakes Water Quality Agreement
HBCD	Hexabromocyclododecane
HIPS	High-Impact Polystyrene
ITT	Identification Task Team
K_{OW}	Octanol Water Partitioning Coefficient
LAMP	Lakewide Action and Management Plan
LRTAP	Long-Range Transboundary Air Pollution
P2	Pollution Prevention
PBDE	Polybrominated Diphenyl Ether
PBT	Persistent Bioaccumulative and Toxic
PCB	Polychlorinated Biphenyl
POP	Persistent Organic Pollutants
SiGL	Science in the Great Lakes
SNUR	Significant New Use Rule
SOLEC	State of the Lakes Ecosystem Conferences
TRI	Toxics Release Inventory
TSCA	Toxic Substances Control Act
UNECE	United Nations Economic Commission for Europe
US	United States of America
US EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
XPS	Extruded Polystyrene

1 Introduction

The purpose of Annex 3 of the Canada-United States Great Lakes Water Quality Agreement (GLWQA) is to reduce the anthropogenic release of chemicals of mutual concern (CMCs) into the Waters of the Great Lakes, recognizing: (1) the importance of life cycle management, (2) that knowledge and information are fundamental to sound management, (3) that CMCs may be managed at the federal, state, provincial, indigenous peoples, and local levels through a combination of regulatory and non-regulatory programs, (4) that international efforts may contribute to reductions from out-of-basin sources, and (5) that the public can contribute to achieving reductions. While there is no requirement in the GLWQA to set reduction targets, consideration should be given to existing guidelines and the work of other Annexes.

In 2016, the two governments designated hexabromocyclododecane (HBCD) as one of eight CMCs. In designating HBCD as a CMC, the Parties have agreed that it poses a threat to the Great Lakes, that current management actions are insufficient, and that further action benefiting the Great Lakes Basin is warranted. These actions are documented in binational strategies that may include research, monitoring, surveillance and pollution prevention, and control provisions. The purpose of the binational strategies is therefore to reduce releases of CMCs by focusing efforts of Governments, agencies, and the public in implementing risk mitigation and management actions. The United States Environmental Protection Agency (US EPA) and Environment and Climate Change Canada (ECCC) are the responsible government Agencies that administer the GLWQA between the two respective nations. Within the United States, the US EPA's Great Lakes National Program Office (GLNPO) coordinates these efforts. Within Canada, ECCC's Ontario Regional Director General's Office coordinates these efforts.

The Parties and their partners will use this strategy as guidance to identify, prioritize, and implement actions to reduce CMCs. Reductions will only be achievable with widespread on-the-ground action, but it will take time to implement actions to the extent that significant reductions are achieved, and it will take time for the aquatic environment to respond. Factors such as climate change, legacy sources, and changing human activities on the landscape make it difficult to predict the rate at which we could see significant changes in the lakes. The ultimate success of the strategy depends on the combined efforts of the Great Lakes community. The strategy and its implementation will be reviewed on a regular basis and reported through the Progress Report of the Parties. While the GLWQA does not provide timelines for strategy implementation, the strategy should be reviewed periodically. Please note that during the time frame of re-evaluation, no new chemical nominations will be accepted.

This HBCD strategy covers a list of 19 management options, in Canada and/or the United States, to address threats to water quality by reducing HBCD releases. These options can be used to help identify, support, or coordinate ongoing or new projects. The options are organized under five categories: Regulations and Other Risk Mitigation and Management Actions; Compliance Promotion and Enforcement; Pollution Prevention; Monitoring, Surveillance, and Other Research Efforts; and Domestic Water Quality. The Parties commit to incorporating, to the extent feasible, respective actions in the CMC strategies in their decisions on programs, funding, and staffing. Implementation will take place, to the extent feasible, by agencies with mandates to undertake work in these areas. As noted in the GLWQA, the Parties' respective obligations are subject to the appropriation of funds in accordance with their respective procedures. Implementation of some CMC actions may be supported through other GLWQA Annexes, for example Annexes 2 (Lakewide Management) and 10 (Science).

2 Chemical Profile

An extensive summary of environmental data and other pertinent information considered as part of the process of designating HBCD as a CMC is available in the Binational Summary Report: Brominated Flame Retardants (PBDEs and HBCD) produced by the Identification Task Team (ITT) (2015).

2.1 Chemical Identity

HBCD is a brominated flame retardant consisting of a 12-membered carbon ring with 6 bromine atoms attached. HBCD is widely used as an additive to impart flame-retardant properties to plastics and textiles (Covaci et al., 2006). HBCD is typically marketed as either a non-specific mixture of HBCD isomers (CASRN 25637-99-4) or as HBCD with bromine atoms at the 1, 2, 5, 6, 9, and 10 positions (CASRN 3194-55-6) (US EPA, 2014). There are 16 possible HBCD stereoisomers (**Figure 1**) (ECCC, 2016a). HBCD mixtures are often dominated by the γ-isomer (approximately 75-89% of the total) with lesser concentrations of α- and β-isomers (typically about 10-13% and 1-12%, respectively) (Letcher et al., 2015). Prior to 2013, when global HBCD phase-out efforts began, HBCD was one of the largest volume flame retardants manufactured globally (ECCC, 2016b).

2.2 Physical and Chemical Properties

HBCD is an off-white, lipophilic powder with low water solubility and a high affinity to particulate matter (NRC, 2000; UNEP, 2015; ECCC, 2016a). The hydrophobic nature and high octanol water partitioning coefficient (K_{OW}) of HBCD enable it to partition into organic phases (e.g., lipids and suspended solids) in the aquatic environment (Marvin et al., 2011). Additional properties of HBCD are listed in **Table 1**.

2.3 Environmental Fate and Transport

HBCD is environmentally ubiquitous, with evidence suggesting adverse environmental and health impacts, including bioaccumulative and biomagnification potential (Marvin et al., 2011). While environmental data specific to the Great Lakes Basin is limited, other international and North American monitoring and surveillance activities suggest that HBCD is highly persistent and is present throughout the Great Lakes Basin (ITT, 2015).

HBCD is subject to long-range transport from its source to remote areas, including the Arctic, where concentrations in the atmosphere have been found to be elevated (ECCC, 2011b). Once released into the environment, HBCD is considered to be persistent and may slowly degrade through abiotic reactions (US EPA, 2016h)(Davis et al., 2005)(Davis et al., 2005)(Davis et al., 2006)(Gerecke et al., 2006). In the environment HBCD is immobile in soil, strongly binds to sediments and suspended solids in water, and slowly volatilizes from moist soils and surface water (US EPA, 2016h). Monitoring studies document the presence of HBCD in the Great Lakes Basin with highest concentrations reported near urban and industrial sources (Marvin et al., 2006; ECCC, 2011b; Letcher et al., 2015). Analyses of sediment core samples collected worldwide show a clear trend of increasing concentrations of HBCD since the 1970s, and stability in deep sediments for periods of more than 30 years (ECCC, 2011b).

2.4 Sources and Releases of HBCD in the Great Lakes

HBCD does not occur naturally in the environment. Sources of HBCD exposure and release sources in the Great Lakes are anthropogenic and may come from local (defined as Canada or the United States) or global sources via long-range transport (ECCC, 2011b).

2.4.1 Uses and Quantities in Commerce

The primary end-use application of HBCD is as a flame retardant in expanded polystyrene (EPS) and extruded polystyrene (XPS) thermal insulation foam boards (US EPA, 2010; US EPA, 2014; ECCC, 2016b). Both products are used in insulation materials in the construction industry. In an effort to meet various federal, state, and municipal building codes seeking to give occupants more time to escape a burning building, flame retardants are used in EPS and XPS to raise ignition temperatures and reduce burn rates, flame spread rates, and smoke. HBCD is used because of its ability to impart sufficient flame retardancy at low concentrations (0.5% - 1%) in both EPS and XPS, without altering the thermal or physical properties of the end-products (US EPA, 2014).

Other minor and historical uses of HBCD include its use in high-impact polystyrene (HIPS) for electrical and electronic parts; in polymer dispersion coating agents for residential, commercial, and military grade textiles (upholstered furniture, transportation seating, automobile interior textiles, wall coverings, and draperies); and in EPS and XPS foam for transportation applications (US EPA, 2014; ECCC, 2016a).

HBCD has been commercially available since the 1960s, and its use in insulation boards started in the 1980s (UNEP, 2010). Global demand for HBCD grew rapidly during the 1990s and early 2000s (UNEP, 2010), which may be due in part to the phase-out of other flame retardants such as polybrominated diphenyl ethers (PBDEs) during this period (ITT, 2015).

In 2003, global demand was 43 million pounds (21,951 metric tons) (UNEP, 2010), and recent estimates indicate that the global market for HBCD in EPS/XPS foams is 66 to 77 million pounds (30,000-35,000 metric tons) (Burridge, 2014). In the United States, an estimated 10 to 50 million pounds (22,000 to 45,000 metric tons) of HBCD were produced annually in the years 1994, 1998, 2002, and 2006 (US EPA, 2016h). As of 2015, more than 66 million pounds (30,000 metric tons) of HBCD were being produced globally, with China being the world's dominant HBCD producer and consumer (Li et al., 2016). In 2016, an estimated 1-10 million pounds of HBCD were manufactured in or imported into the United States (US EPA, 2017).

Market demand for HBCD has significantly declined with the implementation of international bans and the availability of alternatives (US EPA, 2017). The amendment for listing HBCD as a prohibited substance under the Stockholm Convention on Persistent Organic Pollutants (POPs) entered into force in 2015. As a party to the Stockholm Convention, Canada is phasing out the use of HBCD. While the United States is not a party to the Stockholm Convention, manufacturers of construction foams in the United States are converting to alternative flame retardants for their products (Burridge, 2014; US EPA, 2014). In a recent report, it was noted that HBCD is no longer domestically available in the United States, and the use of HBCD in EPS rigid foam insulation has been all but eliminated in the United States (US EPA, 2017).

The maximum concentration of HBCD for use in fabrics and textiles and in rubber and plastic products ranges from 1 to 30% (US EPA, 2010). A majority of HBCD used in textiles is for upholstered furniture in order to meet fire safety laws (Morose, 2006). However, less than 1% of the total commercial and consumer use of HBCD is used for fabrics, textiles, and apparel (US EPA, 2010). In the United States, HBCD is no longer used in consumer textiles applications except for limited use in the automobile industry (US EPA, 2017).

In addition, HBCD is used as a flame retardant in HIPS for electrical and electronic appliances, such as audio-visual equipment and some wire and cable applications (Morose, 2006; ITT, 2015). Less than 10%

of all HBCD used in Europe is used in HIPS (ITT, 2015). The amount of HBCD currently used in HIPS in the United States and Canada is unknown.

2.4.2 Release Sources

Release of HBCD into the environment occurs during production and manufacturing, processing, transportation, use, improper handling, improper storage or containment, point-source discharges, migratory releases from manufactured products, and from disposal of the substance or products containing the substance. HBCD may be released to air, water, soil, and sediment (ECCC, 2011b). **Table 2** outlines potential HBCD uses and release sources that may occur around the globe (UNEP, 2015).

Over the service life of end products, HBCD may be released in vapor or particulates to air or by leaching to water. Releases are expected to be initially to air; however, settling and removal of particulates would ultimately result in losses to soil or water. Losses through abrasion and degradation of polymer end products may also occur. HBCD present in foam insulation is unlikely to be exposed to the weather once building construction is complete (e.g., polystyrene foam products in an installed state). However, prior to and during construction, as well as during demolition, the insulation may be subject to weathering, physical disintegration, and wear, leading to the potential release of particulates containing HBCD. It is expected that release from encapsulated materials would be very low, since dust and fragmentation would likely be minimal and volatilization of HBCD from products would be severely restricted. However, there still may be minimal releases from indoor products that could lead to direct exposures to HBCD.

HBCD encapsulated in textile backcoating materials will have more opportunity for weathering and wear throughout the lifetime of the polymer product, including being washed and chemically cleaned. Losses will likely be primarily to solid waste and wastewater. These losses apply to HBCD in products manufactured in Canada and the United States, as well as to HBCD in finished and semi-finished products imported into the respective countries (ECCC, 2011b).

Products and materials containing HBCD that are disposed in landfill sites may be subject to weathering, releasing HBCD primarily to soil and, to a lesser extent, to water and air. Most of the HBCD released to soil during landfill operations would be expected to sorb to particles and organic matter, remaining largely immobile. Some limited surface transport in water may occur, due to scavenging in rainfall and runoff. However, the low vapor pressure of HBCD suggests that volatilization from the surface of the landfill is unlikely. There is little information on the quantity of HBCD in landfill leachate; however, given the low water solubility of the substance, leaching from the surfaces of polymer products in landfill leachate is expected to be limited. The tendency of HBCD to sorb to particulates, its limited solubility in water, and evidence that it may undergo anaerobic biodegradation all suggest that the risk of groundwater contamination from HBCD-containing products in landfills is probably low (ECCC, 2011b).

Insulation boards can be incinerated with a very high destruction efficiency in advanced municipal solid waste incinerators, cement kiln co-incineration, gas-phase chemical reduction and hazardous waste incinerators. (UNEP 2017). HBCD is unstable at temperatures above 200°C and will, therefore, decompose during burning. Experimental evidence confirms that under some conditions combustion of HBCD and HBCD containing products may release small amounts of brominated analogues of polychlorinated polybrominated dibenzo-p-dioxins (PBDDs) and dibenzofurans (PBDFs). Trace levels of these compounds and their precursors have been measured during combustion of flame-retarded polystyrene materials containing HBCD (ECCC, 2011b). PBDDs and PBDFs present in HBCD waste will likely be destroyed by the very high operating temperatures employed in well-functioning incinerators. However, there is potential for the release of these substances from uncontrolled burns and accidental fires, as well incinerators that are not functioning in accordance with best available techniques and/or best environmental practices (UNEP 2017).

2.4.3 HBCD in Environmental Media

While HBCD monitoring within the Great Lakes Basin has been relatively limited, some data have been collected and are summarized below. HBCD has been detected globally in various environmental media, with the highest concentrations of HBCD being found near urban and industrial areas. HBCD has been measured in air and sediment samples in the Arctic, Scandinavia, North America, and Asia (Hoh and Hites, 2005; US EPA, 2010; ECCC, 2011b; ITT, 2015).

2.4.3.1 In Air

The long-range transport potential of HBCD may depend upon the transport behavior of the atmospheric particulates to which it sorbs (ECCC, 2011b). In 2002-2003, air samples collected from five locations in the East-Central United States were measured for HBCD. Two of the sampled locations were located within the Great Lakes Basin. Concentrations of up to 9.6 pg/m^3 were measured in the particle phase of the Great Lakes Basin air samples (Hoh and Hites, 2005). Of the five locations, the highest mean and median values of HBCD were observed at the Chicago site, and the lowest were seen at a remote location in Michigan (range 0.2 – 8.0 pg/m^3, mean 1.2). When remote locations in the United States were compared to background air concentrations of HBCD collected in Sweden, the Swedish concentrations were slightly higher (2 -5 pg/m^3). It has been suggested that the difference in observed HBCD background concentrations may be a reflection of HBCD replacing penta- and octa-BDE products earlier in Europe than in North America (Hoh and Hites, 2005).

2.4.3.2 In Precipitation

HBCD concentrations in precipitation have also been monitored at select locations around Lake Ontario. One study in particular compared HBCD levels at three locations with varying population densities between 2007 and 2008 (Melymuk et al., 2011). The most densely populated Toronto site was on average four times higher when compared to the other two less-populated sample sites (Burlington, ON and Point Petre, ON); however, the concentrations at all three sites were low, ranging from 0.15 ng/L to 4.40 ng/L (Melymuk et al., 2011).

2.4.3.3 In Surface Water

HBCD has been detected in the surface waters of each of the Great Lakes, ranging from 0.43 to 4.2 pg/L, nearly three orders of magnitude less than the Canadian FEQG for HBCD in water (Venier et al., 2014). Lake Ontario contained the highest concentration of HBCD, followed by Lake Superior > Lake Erie > Lake Michigan, and > Lake Huron (Venier et al., 2014). Venier et al. (2014) observed a correlation between HBCD and other contaminants, which led to the hypothesis that HBCD share similar sources to other chemicals such as PCBs.

In a 2004 study conducted on Lake Winnipeg, northwest of the Great Lakes Basin, the mean dissolved phase concentration of α-HBCD was 0.011 ng/L (ECCC, 2011b; ITT, 2015). Beta- and γ-HBCD isomers were not detected (detection limit 0.003 ng/L). Detection of only α-HBCD in dissolved phase sampling is consistent with its higher aqueous solubility when compared to β- and γ-HBCD isomers (**Table 1**). It is expected that a similar isomer pattern may be found in Great Lakes surface water samples.

2.4.3.4 In Sediments

HBCD released into wastewater streams would likely be transported to a treatment facility. High octanol-water and organic carbon-water partition coefficients suggest that most of the HBCD that reaches a wastewater treatment facility will be concentrated in sludge materials, leaving only a small amount in the final effluent discharges (ECCC, 2011b). In a similar manner, HBCD in surface waters will likely partition into bed sediments (ECCC, 2011b).

Suspended sediments collected along the Detroit River, which flows from Lake St. Clair to Lake Erie, showed a strong association between HBCD presence and urban/industrial activities. In 2001, the annual mean HBCD concentration in suspended sediments collected along the Detroit River ranged from 0.012 ng/g to 1.14 ng/g dry weight, with the highest levels being found downstream of the urban region surrounding the city of Detroit. The widespread occurrence of relatively low concentrations of HBCD suggests that large urban areas may act as diffuse sources of HBCD (Marvin et al., 2006; ECCC, 2011b; Letcher et al., 2015).

Surface sediment samples collected in the Great Lakes region have been monitored through various initiatives. In 2007, 16 surface sediment samples collected throughout the Great Lakes were assessed for HBCD. The average HBCD concentration ranged from 0.04 to 3.1 ng/g dry weight, and was similar to worldwide values (<10 ng/g dry weight) obtained from locations with diffuse HBCD sources (Yang et al., 2012). The HBCD load in sediments collected from Lake Erie and the Detroit River in 2004 was similar, ranging from 0.10 to 1.60 ng/g dry weight (Letcher et al., 2015). Both studies determined the HBCD sediment concentrations in the Great Lakes were significantly less than the Canadian FEQG for HBCD in sediment (1.6 mg/kg dry weight) (**Table 3**).

2.4.3.5 In Biota

In the Great Lake region, HBCD has been detected in fish, Bald Eagle plasma, Falcon nestlings, and eggs from indigenous birds. Herring Gull (*Larus argentatus)* eggs from 15 breeding colonies have been regularly assessed for nearly 40 years in the Great Lakes Basin (Yang et al., 2012). HBCD has recently been added to the list of standard chemicals being monitored in the collected eggs. In 2012, the average total HBCD concentration in each of the Great Lakes breeding colony sites was 13.2 ng/g wet weight (Yang et al., 2012). A 2004 study of pooled homogenates of Herring Gull eggs collected from six colonies around the Great Lakes noted a higher concentration of α-HBCD (ranging from 2.1 ng/g to 20 ng/g wet weight) in the eggs than γ-HBCD (ranging from not detected to 0.67 ng/g wet weight); this is a stark contrast to the ratios found in the original products (Gauthier et al., 2007). The highest levels of α-HBCD were measured at Gull Island on northern Lake Michigan, likely a result of this lake being highly urbanized and industrialized. It should be noted, however, that the southern portions of the lake are more heavily industrialized compared to the areas from which the samples were taken. These findings confirm the presence of HBCD in the aquatic food web associated with Herring Gulls in the Great Lakes, with mother gulls exposed via their diet and subsequent *in vivo* transfer to the eggs (Gauthier et al., 2007; ECCC, 2011b).

Fish are annually collected from each of the Great Lakes and are regularly monitored for a number of chemical classes of interest, one of which is HBCD (US EPA, 2016e). One group focused on HBCD concentrations in Lake Ontario Lake Trout (*Salvelinus namaycush*, a top predator) and several of its major prey species (Tomy et al., 2004). Alpha- and γ-HBCD were detected at all trophic levels, with the highest concentrations present in Lake Trout (mean total HBCD 1.68 ng/g wet weight). Concentrations of α-HBCD were consistently higher than those of γ-HBCD, while β-HBCD was below the method detection limit (estimated at 0.03 ng/g wet weight) in all the species tested (Tomy et al., 2004; ECCC, 2011b). In another study, archival samples from Lake Ontario Lake Trout (age four to five), collected every four to six years (5 individuals per time point, 4 in 1979) contained from 16 ng/g to 33 ng/g lipid weight (2 ng/g to 4 ng/g wet weight) total HBCD (Ismail et al., 2009; ECCC, 2011b). When the archival samples were assessed over time, a significant decline in HBCD concentrations was noted between 1979 and 2004, with the α-isomer dominating the observed concentrations (Ismail et al., 2009; ECCC, 2011b). It has been hypothesized that changes in Lake Trout diet, temporal variation in contaminant loadings, and/or voluntary emission-limiting measures undertaken by industry, may be factors in the observed downward trend in concentrations. Together these studies confirm the occurrence of HBCD biomagnification in the Lake Ontario pelagic food web (Yang et al., 2012).

2.5 High Level Summary of Risks

HBCD is persistent, bioaccumulative, and toxic (PBT); field studies show evidence that bioaccumulation and biomagnification occur within food webs (ECCC, 2011b; Yang et al., 2012). Human exposure of HBCD is evidenced through measurable concentrations in breast milk, adipose tissue, and blood (US EPA, 2014). There is possible human health concern, as animal studies have indicated potential reproductive, developmental, and neurological effects from exposure to HBCD (US EPA, 2014). HBCD has demonstrated toxicity in both aquatic and terrestrial species, with significant adverse effects on survival, reproduction, and development reported in algae, daphnids, and annelid worms. Laboratory studies have shown that algae, fish, invertebrates, and soil-dwelling organisms exhibit adverse effects at environmentally relevant concentrations of HBCD (US EPA, 2012). Recent studies indicate acute toxicity to fish embryos, and sub-lethal impacts on the normal functioning of liver enzymes and thyroid hormones in fish at environmentally relevant concentrations (Palace et al., 2008; Deng et al., 2009; US EPA, 2012). In mammals, high dose studies have shown reproductive, developmental, and behavioral effects (ECCC, 2011b; US EPA, 2012).

The risk assessment of HBCD under CEPA (ECCC, 2011b) indicated that the widespread presence of HBCD in the environment warrants concern in light of strong evidence that the substance is environmentally persistent and bioaccumulative. In addition, the analysis of risk quotients in Canada showed that current HBCD concentrations in the Canadian environment have the potential to cause adverse effects in populations of pelagic and benthic organisms, but are currently unlikely to result in direct adverse effects to soil organisms and wildlife (ECCC, 2011b).

Consumption of tainted fish is potentially a minor human exposure route. While there are very few human health guidelines than could be used for HBCD, monitoring programs are starting to incorporate HBCD into the standard set of analyses. In June 2017, US EPA (2017) outlined the scope of future risk evaluations for HBCD (https://www.epa.gov/sites/production/files/2017-06/documents/hbcd_scope_06-22-17_0.pdf).

The primary human exposure to HBCD may be through inhalation of airborne dust, ingestion, dermal contact, and, in very limited scenarios, inhalation of vapor (US EPA, 2014). The textile applications of HBCD are expected to present a greater risk of human HBCD exposure than flame-retarded insulation. HBCD is an additive flame retardant that is not chemically bonded to the treated material, and therefore there is a potential risk for migration and human exposure (ECCC, 2011b; US EPA, 2014). Currently, there is no readily available HBCD occupational exposure information for workers (US EPA, 2014). In Canada, a limited human health hazard risk characterization for HBCD indicated that HBCD does not have genotoxic potential *in vitro* or *in vivo*, was not carcinogenic, and did not cause systemic toxicity in a chronic oral feeding study (ECCC, 2011b). The Canadian report also concluded that HBCD is not entering the environment in a quantity or concentration or under conditions that constitute or may constitute a danger in Canada to human life or health (ECCC, 2011b).

3 Existing HBCD Management/Control Policies, Regulations, and Programs

3.1 United States

3.1.1 Existing Statutes and Regulations

The most notable regulation for HBCD in the United States is a rule under Toxic Substances Control Act (TSCA). In March 2012, EPA proposed a significant new use rule (SNUR) for HBCD under section 5(a)(2) of TSCA. On September 23, 2015, this SNUR became a significant new final rule. This rule designates "use in consumer textiles, other than for use in motor vehicles" as a significant new use. The rule required persons intending to manufacture, import, or process HBCD for use in consumer textiles to register their activities within 90 days before beginning their activities. The required notification provides US EPA with the opportunity to evaluate the intended use and, if appropriate, to prohibit or limit that activity before it occurs (US EPA, 2016f).

On November 28, 2016, US EPA finalized a rule adding an HBCD category to the Toxic Release Inventory (TRI) list of reportable chemicals with a 100-pound reporting threshold (US EPA, 2016b). An estimated 101 facilities from across the United States began collecting HBCD release information on January 1, 2017, with the first reports due July 1, 2018 (US EPA, 2016a). This rule will significantly increase the currently available HBCD release source information for the United States.

In December 2016, in accordance with the Lautenberg Chemical Safety Act, HBCD was among the 10 top chemicals to receive initial evaluation. The initial scope of the risk evaluation for HBCD was published in June 2017. This document outlines the initial analysis plan for conducting a systematic review of HBCD risk information that will be used to develop an analysis plan for the risk evaluation of HBCD by the US EPA (US EPA, 2017).

Among the Great Lakes States, only Minnesota has an HBCD-specific regulation. Under the Toxic Free Kids Act of 2009 (Minn. Stat. 2010 116.9401-116.9407), HBCD is classified as a "Chemical of High Concern" (US EPA, 2017). No additional HBCD-specific regulations currently exist in any of the Great Lakes Basin States. Since HBCD is a chemical of high concern, the Minnesota Pollution Control Agency is tasked to make recommendations about mechanisms to reduce and phase out the HBCD use in children's products (MPCA, 2010).

3.1.2 Pollution Prevention Actions

Due to the limited knowledge base of HBCD use and release information in the United States, few pollution prevention actions have formally been conducted. However, in light of international bans and the availability of alternative flame retardants for products, many manufactures have significantly reduced HBCD usage or eliminated it from their products. HBCD use in consumer textile applications outside of the automobile industry have also been eliminated (US EPA, 2017). A recent report noted that HBCD is no longer in regular use, and is only used in specialty coatings at certain automobile manufacturing facilities in the United States. However, it was also noted that HBCD may still be present in replacement parts that were imported or manufactured prior to phase-out (US EPA, 2017).

3.1.2.1 Pollution Prevention (P2) Programs

The US EPA and individual States have active Pollution Prevention (P2) programs that seek to reduce, eliminate, and/or prevent pollution at its source. It is anticipated that, as HBCD data from TRI and flame-retardant alternatives research accumulates, P2 programs in the United States will come into effect in the future.

3.1.2.2 Alternatives to HBCD

Due to the limited knowledge base for HBCD, the United States Federal government has been actively evaluating HBCD since the early 2000's. In 2011, US EPA formally began assessing and designing flame-retardant alternatives to HBCD. US EPA's assessment of flame-retardant alternatives for HBCD was opened to public comment in 2013 before the Final Design document was published in 2014 (US EPA, 2014). This document evaluates and compares potential hazards associated with HBCD and three proposed alternatives, as well as multiple performance considerations for the end product (**Table 4**). Brominated flame retardants were determined to be the only commercially available option that can be used at concentrations that do not negatively alter the physical properties of the foam. Based upon the outlined criteria and guidance, the document identifies butadiene styrene brominated copolymer as a replacement to HBCD in EPS and XPS insulation manufacturing. While environmental studies are needed, butadiene styrene brominated copolymer is anticipated to be safer than HBCD for multiple endpoints (US EPA, 2014). EPS and XPS foams are already being produced and commercially used with butadiene styrene brominated copolymer rather than HBCD. Future alternatives assessments may consider whether chemical flame retardants are in fact needed or if other approaches (e.g., product redesign) could be undertaken to meet all or some needs (IJC, 2016).

3.1.3 Risk Management Actions

The Great Lakes Restoration Initiative (GLRI) is a United States initiative launched in 2010 to accelerate efforts to protect and restore the Great Lakes ecosystem. Under the GLRI, GLNPO assists in the removal of sediments containing pollutants under the Great Lakes Legacy Act (GLLA). The GLLA is a voluntary cost-share program in the United States designed to remediate contaminated sediments within the 43 designated Great Lakes Areas of Concern (AOCs). Between 2004 and 2015, GLLA has remediated more than 4 million cubic yards (3 million cubic meters) of contaminated sediment (US EPA, 2016c). While HBCD contamination was not a targeted contaminant during these remediation efforts, HBCD has been shown to be co-located with other contaminants; therefore, AOC remediation efforts may also address HBCD (Venier et al., 2014).

3.1.4 Monitoring, Surveillance, and Other Research Efforts

Environmental monitoring and surveillance of Great Lakes have been conducted through a number of United States parties. Local, regional, institutional, Tribal, and federal entities have conducted independent and cooperative studies assessing the conditions and status of the Great Lakes for many years.

Much of the data collected has been placed in the Great Lakes Environmental Database (GLENDA). GLENDA is a database for the collection and storage of environmental data maintained by GLNPO. Air, water, biota, and sediment data are all compiled in the system for users of Great Lakes data (US EPA, 2016d). Science in the Great Lakes (SiGL) Mapper (https://sigl.wim.usgs.gov/sigl/) is an additional searchable database tool developed by the US Geological Survey (USGS) that allows Great Lakes stakeholders to coordinate and collaborate monitoring and restoration activities on the Great Lakes (US EPA, 2015). These databases enable researchers to use historic data from across the region to solve complex chemical, biological, and physical relationships that might lead to more advanced methods for pollution identification and remediation actions.

Great Lakes Specific Efforts. The US EPA, through GLNPO, is mandated, via Section 118 of the Clean Water Act, "to establish a Great Lakes system-wide surveillance network to monitor the water quality of the Great Lakes, with specific emphasis on the monitoring of toxic pollutants." As part of its core mission, GLNPO operates a number of monitoring programs for toxic chemicals in Great Lakes media (fish, air, sediment). These long-term programs are focused on the tracking of trends of environmental pollutants across the basin to assess environmental health. While HBCD has not been of interest in the past, future initiatives may expand the chemical agents of interest included in such projects.

Additionally, GLNPO supports work on toxic chemicals, including HBCD, with other partners via grants, interagency agreements, and collaborations to address chemical issues as they relate to human health. HBCD results are reported through State of the Lakes Reports, LAMPs, and peer-reviewed literature, and continued reporting is proposed in Section 5.4.

3.1.5 US EPA Guidelines and Standards

To date, there are no standards or recommendations that have been published at the federal or state level for HBCD concentrations or HBCD-containing waste concentrations in workplace air, drinking water, environmental waters, or foodstuffs. As mentioned above, TSCA SNUR designations of HBCD, its listing as a Lautenberg Chemical Safety Act chemical, and its recent addition to TRI may be used to assist in the development of future federal guidelines. At the state level, only the State of Minnesota has HBCD-specific regulations that classify it as a “Chemical of High Concern” (Minn. Stat. 2010 116.9401-116.9407), making it a target for mechanisms to reduce usage.

3.2 Canada

EPS and XPS foam in building and construction applications accounted for approximately 99% of HBCD use in Canada in 2012 (ECCC, 2016b). While HBCD is not manufactured in Canada, it was imported into Canada mainly for the production of intermediate and finished EPS and XPS products. A study conducted for ECCC estimated that in 2012 approximately 800,000 pounds (363 metric tons) of HBCD were imported for the production of XPS foam and EPS resin (ECCC, 2016b). Of this total, approximately 60,000 pounds (27 metric tons) of HBCD were exported in EPS resin, which translates to approximately 740,000 pounds (336 metric tons) of net HBCD consumption in Canada (ECCC, 2016b). This study also reported that there may be a low volume of imports of HIPS and textiles into Canada containing HBCD in very niche applications (ECCC, 2016b).

While only a small amount of HBCD is expected to be released from in-place finished and semi-finished products, post-consumer end-of-life disposal of HBCD products is a potential source of HBCD emissions to both indoor and outdoor environments (Li et al., 2009). It is estimated that 92.4% of imported HBCD will eventually be landfilled as a component of EPS and XPS foams, and 7.5% of the imported HBCD was exported in EPS resin. The remaining 0.1% of imported HBCD was released during the manufacture of EPS and XPS foams and resins, or during use of EPS and XPS foams (ECCC, 2016b).

3.2.1 Federal Risk Management Actions

Under the Chemicals Management Plan in Canada, an environmental objective is a quantitative or qualitative statement of what should be achieved to address environmental concerns identified during a risk assessment. The existing environmental objective for HBCD is virtual elimination of releases into the environment (ECCC, 2011b). Risk management objectives are expected to be achieved for a given substance by the implementation of regulations, instrument(s), and/or tool(s). The existing risk management objective for HBCD is to achieve the lowest level of release of the substance that is technically and economically feasible into the Canadian environment (ECCC, 2011a).

The *Regulations Amending the Prohibition of Certain Toxic Substances Regulations, 2012,* entered into force in December 2016, adding five substances, including HBCD to the *Prohibition of Certain Toxic Substances Regulations 2012* (ECCC, 2016b). Prior to the amendments, there were no risk management

instruments in place for preventative or control actions for HBCD in Canada. Under the amended regulations, the manufacture, use, sale, offer for sale, or import of HBCD, as well as EPS and XPS foam and their intermediary products containing HBCD used in building construction applications, with a limited number of exemptions, are prohibited as of January 1, 2017.

The Regulations do not prohibit:

- The import, manufacture, use, sale, or offer for sale of products containing HBCD other than EPS and XPS (and intermediary products) for a building/construction application
- The use, sale, or offer for sale of HBCD manufactured or imported before January 1, 2017
- The use, sale, or offer for sale of EPS and XPS (and intermediary products) for a building/construction application, if manufactured or imported before January 1, 2017
- The import, manufacture, use, sale, or offer for sale of HBCD or EPS and XPS foam (or intermediary product) containing it, if HBCD is incidentally present.

The regulations do not apply to feedstock contaminants that are destroyed during processing, or to aspects that are regulated by or under any other act, such as hazardous wastes and pest control products. Furthermore, the regulations do not apply to HBCD or products containing HBCD that are to be used in a laboratory for analysis, in scientific research, or as a laboratory analytical standard.

At this time, the Government of Canada is building its knowledge on end-of-life management practices addressing various substances, including HBCD, in Canada, as well as on the presence and potential releases of toxic substances and other substances of concern, in waste management facilities in Canada.

The Government of Canada has been working with the automotive sector through non-regulatory measures to work towards achieving a full phase-out. As of October 2016, they have received letters of commitments from all Canadian automotive manufactures stating their intention to phase out HBCD. The letters state that Canadian manufacturers have either already phased out HBCD or commit to doing so by 2020 at the latest.

3.2.2 Alternatives to HBCD

Potential alternatives to HBCD, as identified by the US EPA Design for Environment Program, have been assessed by ECCC under the New Substances Program. Specifically, ECCC has evaluated butadiene styrene brominated copolymer and determined that it is not toxic under CEPA.

3.2.3 Monitoring, Surveillance, and Other Research Efforts

The Government of Canada has been monitoring HBCD in the Canadian environment (since 2008) and landfill leachate (since 2009) under the Chemicals Management Plan. This monitoring information could be used to assess the progress and effectiveness of future risk management actions that may be taken by the Government of Canada and to better understand potential environmental exposure from these sources. The media being monitored include wildlife, fish, air, and sediment (ECCC, 2011a).

3.2.4 Environment and Climate Change Canada Quality Guidelines and Standards

In May 2016, Canada published FEQGs for HBCD in water, sediment, and mammalian wildlife diet (**Table 3**). FEQGs serve three functions: (1) they can be an aid to prevent pollution by providing targets for acceptable environmental quality; (2) they can assist in evaluating the significance of concentrations of chemical substances currently found in the environment (monitoring of water, sediment, and biological tissue); and (3) they can serve as performance measures of the success of risk management activities.

The use of FEQGs is voluntary unless prescribed in permits or other regulatory tools. Thus, FEQGs, which apply to the ambient environment, are not effluent limits or "never-to-be-exceeded" values, but may be used to derive effluent limits (ECCC, 2016a). Current knowledge indicates that all FEQGs are being met by orders of magnitude.

3.3 Binational

3.3.1 Lakewide Action and Management Plans

The purpose of the LAMP program is to coordinate efforts to assess, restore, protect, and monitor the ecosystem health for each of the Great Lakes (US EPA, 2004; US EPA, 2016g). CMCs will be considered as future priority for monitoring and surveillance through the Lake Partnerships.

3.3.2 Cooperative Science and Monitoring Initiative

One aspect of the GLWQA is the establishment of a Cooperative Science and Monitoring Initiative (CSMI) Task Team through Annex 10. The charge of the CSMI is to implement a joint United States/Canadian effort to provide environmental and fishery managers with the science and monitoring information necessary to make management decisions for each Great Lake. A five-year rotating cycle in which the lakes are visited one per year is followed by an intensive CSMI field year, including connecting channels beginning in 2009. By studying one Great Lake per year, science and monitoring activities can focus on information needs not addressed through routine agency programs, and specific science assessments can be coordinated. Individual Lake Partnerships identify science needs according to the CSMI schedule, and the Task Team implements these recommendations, as appropriate.

3.4 International

Several international agreements have been established to limit the global availability and use of HBCD in an attempt to limit the overall number of environmental sources of HBCD.

3.4.1 United Nations Economic Commission for Europe Protocol on Persistent Organic Pollutants

In 1998, the Executive Body (EB) of UNECE adopted the Protocol on Persistent Organic Pollutants, and singled out 16 substances for elimination. In December 2009, the EB of the Commission agreed that HBCD also meets the criteria for being a POP under the Convention set out in EB decision 1998/2, that is: HBCD has the potential for long-range transport and is found in remote regions; it has the potential to adversely affect human health and/or the environment; it is persistent and bioaccumulates; and its release into the environment is wide-dispersive (UNECE, 2009). Therefore, potential risk management options are currently being considered (EEA, 2016).

3.4.2 The Stockholm Convention on Persistent Organic Pollutants

The Conference of the Parties to the Stockholm Convention on Persistent Organic Pollutants decided at its sixth meeting, in 2013, to list HBCD in Annex A with specific exemptions. The objective of the Stockholm Convention is to protect human health and the environment from POPs and a listing in Annex A aims to eliminate the production, use, import, and export of the substance. Canada signed and ratified the Convention in 2001, and it entered into force in 2004. The United States has signed the Convention, but has yet to provide ratification, acceptance, approval, or accession, and therefore in the United States the Convention has not yet entered into force. Canada has not yet ratified the listing of HBCD to the Convention (UNEP, 2015).

For HBCD, parties may request a five-year specific exemption for the production of HBCD for EPS and XPS foams in buildings and/or for the use of EPS and XPS containing HBCD in buildings. Each party that has registered for an exemption for the production of HBCD for EPS and XPS in buildings must take necessary measures to ensure that EPS and XPS containing HBCD can be easily identified by labelling or other means throughout its life cycle (UNEP, 2015).

3.4.3 The Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and their Disposal

The Basel Convention objective is to protect human health and the environment against the adverse effects of hazardous wastes. Canada signed and ratified the Convention in 1992 and the Convention entered into force in 1992. The U.S. is not a party to the Basel Convention. A key provision of the Convention is to promote the environmentally sound management of hazardous wastes, including POP wastes.

The Conference of the Parties to the Basel Convention adopted technical guidelines on the environmentally sound management (ESM) of POP waste in 2017 (UNEP 2017) and technical guidelines on the ESM of HBCD wastes in 2015 (UNEP 2015a). These guidelines provide detailed guidance on reducing or eliminating POP releases to the environment from waste disposal and treatment processes and the identification and environmentally sound management of HBCD wastes.

4 Gap Analysis

4.1 Gaps and Needs for Action

There are a number of unknowns in both Canada and the United States concerning unquantified HBCD sources. Since the addition of HBDC to the *Prohibition of Certain Toxic Substances Regulations, 2012* in Canada, the only remaining sources of HBCD to the environment from Canada will be imported products containing HBCD, other than EPS and XPS used in building and construction (expected to be minimal in quantity), and all products (including EPS and XPS used in building and construction) that were in use or existing prior to January 1, 2017. As of October 2016, Canada has received letters of commitments from all Canadian automotive manufacturers stating their intention to phase out HBCD. The letters state that Canadian manufacturers have either already phased out HBCD or commit to doing so by 2020 at the latest. The United States does not have a phase-out deadline for HBCD, nor does the United States have environmental guidelines for drinking water, open waters, sediments, or biota concentrations. However, multiple producers have already eliminated or are in process of eliminating HBCD from their processes (US EPA, 2017).

Emissions from HBCD-containing materials have the potential to be long-term sources to the environment. However, no information is available on the likely rate of future emissions from such articles. The life span of polystyrene foam in buildings is reported to be 30-50 years (UNEP, 2011). Releases from these existing stocks of EPS/XPS may be more significant in the future, particularly from 2025 onwards, as buildings with EPS and XPS containing HBCD are refurbished or demolished and HBCD-containing products enter waste streams (UNEP, 2011; US EPA, 2017).

Although HBCD is targeted under international agreements, some countries continue to manufacture and use HBCD, therefore long-range transport is a likely continued source of HBCD to the Great Lakes Basin. HBCD in Great Lakes air, water, sediment, fish, and wildlife species is beginning to be routinely monitored. Additional monitoring for HBCD in environmental media is needed in the Great Lakes Basin, in areas with the potential to affect the Great Lakes Basin (e.g., the remainder of State areas not within the Basin, transporters through the Basin, etc.), and nationally. Additional monitoring should acquire information on time series and scales that allow HBCD levels to be better known and modelled nationally, particularly in cases involving products or sources distributed in commerce, including but not limited to the Basin.

Furthermore, there is a need to ensure that chemical data collected by US EPA, ECCC, State, Provincial, Tribal, First Nations, Métis, and other government programs are consistent, standardized, and structured to allow for improved binational monitoring for HBCD and HBCD-containing products. Working to ensure uniformity of data can be helpful in ensuring that independent data collection actions can be used collectively to address and identify HBCD concerns. Ideally, a repository in which data on a binational level can be cataloged by media (e.g., air, water, land, biota) and accessed by external stakeholders should be implemented.

Several knowledge gaps exist that limit risk management actions for HBCD. Some areas that have been identified include:

- *Releases from Products in Use.* Addressing releases of HBCD from construction materials or other products currently in use. This source of release is relatively minor; however, it does remain a concern. This would include HBCD releases from:
    - HBCD in EPS and XPS building/construction materials that are currently in place
    - HBCD in EPS and XPS but used in areas other than building/construction
    - HBCD in products that are not EPS and XPS foams (e.g., specialty fabrics)
- *Releases from Waste Products*. The majority (over 90%) of HBCD contained in materials is expected to end up in landfills. There is a gap in understanding the extent to which HBCD is released from different waste operations (e.g., landfilled wastes, incinerators, etc.)(ECCC, 2016b).
- *Monitoring Needs*. There is a need to initiate/continue activities to monitor long-term isomer-specific trends in water, air, sediment, and biota (top-predator fish and Herring Gull eggs) in the Great Lakes, in order to establish and continue to track long-term trends; track long-range atmospheric transport and deposition; establish environmental concentration standards; and evaluate the performance of existing and forthcoming risk management activities.
- *Environmental Standards*. There are currently no environmental water quality, biota/diet, or sediment concentrations standards in effect in the United States.
- *Clarification of Product Disclosure Requirements*. Clarification is needed in the United States to assist importers and users of finished products on the disclosure requirements for HBCD content of finished products.

4.2 Exceedances of or Non-compliance with Environmental Quality Guidelines

Data from the Great Lakes Basin for HBCD are limited. It is therefore difficult to determine whether relevant guidelines and/or benchmarks are being exceeded, and to establish whether spatial or temporal trends exist at this time. However, exceedances of the Canadian FEQG levels have not been found in the limited available data collected in the Great Lakes surface waters or sediments (**Table 3**).

5 Risk Mitigation and Management Options to Address Gaps

The actions highlighted herein represent both new and the continuation of current risk management and other actions that will address the gaps outlined and may result in measurable (either qualitatively or quantitatively) human health and/or environmental benefits, or enhanced understanding of HBCD sources, fate, and human health or environmental effects.

5.1 Regulations and Other Risk Mitigation and Management Actions

In Canada, the manufacture, import, use, sale and offer for sale of HBCD and certain products containing it are prohibited under the *Prohibition of Certain Toxic Substances Regulations, 2012* as of January 1, 2017. In the United States, use of HBCD in textiles requires US EPA notification per the 2015 SNUR; however, there is no formal phase-out schedule for HBCD use in the United States.

FEQGs have been established in Canada as benchmarks for environmental HBCD concentrations. Comparable environmental standards have not been established in the United States. Therefore, efforts should focus on developing both environmental standards and drinking water standards for the United States.

Alternatives to HBCD are being sought and implemented for use within EPS and XPS foams, and for use in specialty fabrics. Continuation of alternatives research is needed to ensure that the product performance of the suggested alternatives is appropriate and that all environmental impacts of the alternative chemicals are understood.

Summary of Regulations and Other Risk Mitigation and Management Actions Strategy Options

- Generate phase-out deadlines for HBCD usage at the federal level (US)
- Establish environmental and drinking water standards at the federal level (US)
- Evaluate alternatives to HBCD (US)
- Quantify releases of HBCD from various products during their life-cycle (production, use, storage, and disposal) (Canada and US)

5.2 Compliance Promotion and Enforcement

The Canadian *Prohibition of Certain Toxic Substances Regulations, 2012* prohibits the manufacture, use, sale, offer for sale, and import of HBCD and certain products containing HBCD.

In the United States, HBCD was added as a TRI reportable chemical in November 2016. Beginning in 2017, facilities that manufacture, process, or otherwise use HBCD in amounts above the 100-pound reporting threshold level must report environmental releases and other wastes to TRI (US EPA, 2016b). Enforcement of such reporting is a critical step to understanding the location and extent of potential HBCD releases, and their potential end-of-life disposal routes.

Disposal of HBCD-containing products is of concern; therefore, both nations need to implement methods to evaluate the product life cycle and to determine the most appropriate measures to ensure the environmentally sound management of HBCD wastes, in alignment with ongoing international guidelines and activities. Alternatives to HBCD are available for use in EPS and XPS foams, and should be developed for use in specialty fabrics. Additional work is needed to ensure that the product performance of the suggested alternatives is appropriate, and that all environmental impacts of the alternative chemicals are understood.

Summary of Compliance Promotion and Enforcement Strategy Options

- Promote compliance with the *Prohibition of Certain Toxic Substances Regulations, 2012* (Canada)
- Promote compliance with TRI database reporting (US)
- Identify and establish safe disposal methods for HBCD-containing products (US)
- Promote safe disposal of HBCD-containing products (Canada and US)

5.3 Pollution Prevention

User-friendly documents are needed to educate and engage the general public in efforts to reduce the potential for HBCD release or exposure and present alternative flame retardants for products to use. Documents should highlight the potential for HBCD exposure and outline waste mitigation measures for ensuring proper waste handling procedures during renovation projects. Such documentation may help to prevent low-level HBCD pollution from being incorporated into general solid waste streams, and provide awareness regarding potential HBCD sources.

Manufacturers are encouraged to examine flammability standards of their products and consider whether chemical flame retardants are in fact needed or if other approaches (e.g., product redesign) could be undertaken to meet all or some needs.

US EPA's TRI database can be used to track progress in reducing waste generation. While it is currently unclear if enough potential HBCD sources will be captured via TRI to produce meaningful progress reports across all sectors, the TRI database should be maintained and leveraged to maximize P2 activities being conducted by industries in the Great Lakes region. Highlighting pollution prevention successes in the Great Lakes Basin may be beneficial in increasing awareness, coordinating P2 efforts in similar sectors throughout the Basin, and furthering the reduction of HBCD in the environment. Waste reduction success stories may be noted in region-specific journals, websites, and/or at conferences.

Summary of Pollution Prevention Strategy Options

- Increase public outreach and educate the public and facility staff on potential sources of HBCD and proper actions to follow should HBCD-containing materials be found (US)
- Educate the public on less toxic flame retardants (US)
- Encourage industries to use P2 activities and track their efforts in the TRI database (US)
- Highlight and share P2 successes (US)
- Support stakeholders that are seeking alternatives to brominated flame retardants, including HBCD (Canada and US)

5.4 Monitoring, Surveillance, and Other Research Efforts

Existing research does not present a complete understanding of the status and trends of HBCD in the Great Lakes environment. The US EPA and ECCC have coordinated efforts to publish and report research efforts (ECCC and US EPA, 2011). Additional monitoring and surveillance reports have been published in peer-reviewed journals, websites, and social media. Each form of reporting is designed to target specific audiences to maximize the application of the results. Results of future monitoring efforts should continue to be published in multiple formats to effectively communicate changes observed in multiple media (air, sediment, and biota [top-predator fish and Herring Gull eggs]) in the Great Lakes region.

The State of the Lakes Reporting is a binational undertaking where Great Lakes decision-makers and scientists have the opportunity to receive comprehensive, up-to-date, clear, and concise information on the state of the Great Lakes (ECCC and US EPA, 2011). The addition of HBCD as a CMC may increase future HBCD-focused initiatives. The continuation of such efforts by the two nations will be invaluable for understanding the overall status of HBCD in the Great Lakes Basin. Monitoring efforts undertaken by both nations should be coordinated to aid in acquiring comparable analytical data that can be used to build a national and/or international decision-making framework.

The development of a cost-effective and useful means of collecting HBCD concentrations from a variety of sources is essential. Developing a passive sampler capable of monitoring HBCD levels could be used to better understand the spatial distribution and behavior of HBCD in the Great Lakes, and the region as a whole. Source tracking HBCD contamination may be a need in the future. Efforts such as Project Trackdown that uses a multimedia weight-of-evidence approach for tracing polychlorinated biphenyl (PCB) sources in the Great Lakes may be a model system for future HBCD studies (Benoit et al., 2016). In addition, future monitoring efforts should be designed so that the resultant data can be compared among research teams and to historical data.

Summary of Monitoring, Surveillance, and Other Research Strategy Options

- Monitor HBCD in Great Lakes environmental media (air, sediment, waters, fish, and other wildlife) and publish results in a variety of publications to maximize the intended audience (Canada and US)
- Develop models to track long-range atmospheric HBCD transport and deposition into the Great Lakes Basin and degradation pathways of various HBCD stereoisomers found in the Great Lakes Basin (US)
- Use monitoring and modeling to better characterize HBCD sources as a basis for potential actions, measuring progress, and formulating an international decision-making framework (Canada and US)
- Develop cost-effective tools for monitoring HBCD concentrations from various sources (Canada and US)
- Develop structured data systems and plans for monitoring HBCD sources, manifests, and product tracking (US)

5.5 Domestic Water Quality

Domestic waters include all water used for indoor and outdoor household purposes. Currently there are no HBCD drinking water standards in either the United States or Canada.

Summary of Domestic Water Quality Strategy Options

- Develop and implement appropriate domestic water quality standards for drinking water and surface waters (US)

6 Conclusions

Under Annex 3 of the GLWQA, HBCD has been identified as a CMC that originates from anthropogenic sources. The binational objective of the HBCD Strategy, comprising joint and individual actions of the Parties, is to reduce the anthropogenic release of HBCD in the Great Lakes Basin ecosystem and better understand the presence, fate, and transport of HBCD in the environment.

Binational efforts are needed to reduce the risks that HBCD poses to human health and/or the environment. Binational cooperation is needed to coordinate monitoring and surveillance efforts, maximize research initiatives to identify HBCD sources, and cost-effectively monitor and track HBCD concentrations in multiple media (wastes, soil, water, air, tissues, etc.).

A broad audience of Great Lakes stakeholders who are committed to protecting and restoring the Great Lakes ecosystem is encouraged to provide input on the risk mitigation and management options outlined in this document. Continued progress in seeking novel approaches and/or improving upon existing ways to mitigate and manage HBCD risks will improve the health of the ecosystem and residents of the Basin, and will preserve the quality of the Great Lakes for future generations.

7 Tables

Table 1. *Physical and Chemical Properties of HBCD*

Property	**HBCD**
Formula	$C_{12}H_{18}Br_6$
Molecular Weight	641.7
Color	White to off-white
Physical State	Solid/powder
Melting Point, °C	185-195
Water Solubility, mg/L at 25°C	0.0034, average
α-	0.00488
β-	0.00147
γ-HBCD	0.00208
Partition Coefficient	
Log K_{OW}	5.6 to 5.81
Log K_{OC}	5.1
Vapor Pressure, mm Hg at 25°C	$4.7x10^{-7}$
Henry's Law Constant, Pa-m^3/mol at 25°C	0.14 to 68.8

Sources: National Research Council (2000) and ECCC (2016a)

Table 2. Potential HBCD Release and Exposure from Global Sources

Source	Release Media	Examples of Waste Types
HBCD Manufacture		
Production process	Solid waste, off-gas*, waste water	Dusts, residues and waste products from manufacture, wastewater treatment sludge, discarded waste filter cloth
Products and packing process	Solid waste, dust particles	Waste products, packaging wastes
HBCD Use (Process)		
Building materials production	Off gas, waste water, solid waste	Dust, residues and process waste products, packaging wastes and wastewater treatment sludge
Furniture manufacturing	Off gas, waste water, solid waste	Dust, residues and process waste products, packaging wastes and wastewater treatment sludge
Textile production	Off gas, waste water, solid waste	Dust, residues and process waste products, packaging wastes, clothing and wastewater treatment sludge
Production of High Impact Polystyrene (HIPS)	Off gas, waste water, solid waste	Dust, residues and process waste products, packaging wastes and wastewater treatment sludge
Consumer Use		
Leaching and volatilization from products	Off gas, wastewater, solid waste	Dust particles, waste residue
Fires	Off gas, wastewater, solid waste	Waste residues, contaminated soil
Waste Recycling and Disposal		
Building material waste recycling/disposal	Solid waste	HBCD-containing EPS and XPS, wastes from recycling or from separation of HBCD from polymer
Waste plastic recycling/disposal	Solid waste, wastewater	Waste HIPS and other plastics, electrical and electronic plastic shells, circuit boards, and wire
Incineration	Exhaust gas, solid waste, wastewater	Solid residues (ash, flue gas cleaning residues), exhaust gas
Landfill	Solid waste, leachate, air releases (fires)	Leachates, fumes from open burning

* The volatilization of HBCD from products that contain HBCD.
Source: UNEP (2015)

Note that not all of these examples apply to the Great Lakes Basin.

Table 3. *Canadian Federal Environmental Quality Guidelines for HBCD and Great Lakes Environmental Concentrations*

Media	Canadian FEQG	Great Lakes Concentrations
Water	0.56 mg/L	0.00000000043 to 0.0000000042 mg/L (0.43 to 4.2 pg/L)
Sediment*	1.6 mg/kg dw	0.000012 to 0.00114 mg/kg dw (0.012 to 1.14 µg/kg dw)
Mammalian Wildlife Diet	40 mg/kg food ww	Not Available

***Normalized to 1% organic carbon; dw = dry weight; ww = wet weight**
Sources: ECCC (2011b); ECCC (2016A); Venier (2014)

Table 4. *Properties Considered in Determining Alternative Flame Retardants in EPS and XPS*

Property Type Considered	Example
Primary Properties of Rigid Foam	Lifetime R-value Compressive Strength Flexural Strength Dimensional Stability Moisture Resistance
Fire Safety Properties	Ignition Temperature Burn Rate Flame Spread Rate Smoke Generation
Environmental Considerations	Pollution generated in manufacture process Reuse/Recycle Capabilities Environmental impact of the raw materials
Material Safety Considerations	Hazardous chemical components Presence of blowing agents
Additional Performance Characteristics	Water vapor transmission (permeance) Corrosivity Material weight Resiliency Resistance to mold growth and microbial degradation Acoustical energy absorption Usage in retrofits versus new construction Anticipated lifespan

Source: US EPA (2014)

8 Figures

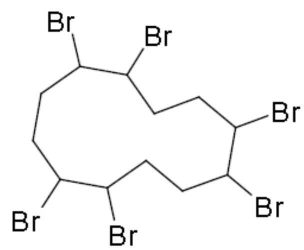

Figure 1. *Representative Structure of HBCD.*

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