DRAFT

Binational Strategy for Polybrominated Diphenyl Ethers (PBDEs) Risk Management

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

Draft prepared by Environment and Climate Change Canada and the United States Environmental Protection Agency

Disclaimer

The purpose of this document is to propose polybrominated diphenyl ethers (PBDE) 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 polybrominated diphenyl ethers (PBDEs), 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 PBDEs to focus 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, and the public to in implementing risk mitigation and management actions aimed at reducing PBDEs 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; Compliance Promotion and Enforcement; Pollution Prevention; Monitoring, Surveillance, and Other Research; 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.

PBDEs are a group of chemical compounds comprised of 209 theoretical congeners, a sub-group of which have been used as flame retardants in a wide variety of products since the 1970s. PBDEs were sold commercially in three mixtures identified by their primary homolog group of individual congeners: pentabromodiphenyl ether (c-pentaBDE), octabromodiphenyl ether (c-octaBDE), and decabromodiphenyl ether (c-decaBDE). PBDE congeners as a chemical class are persistent, toxic and bioaccumulate in tissue, which can result in high exposure levels in humans and other biota.

PBDEs were not manufactured in Canada, and regulations came into force in 2008 prohibiting the manufacture of PBDEs in Canada (tetraBDE, pentaBDE, hexaBDE, heptaBDE, octaBDE, nonaBDE and decaBDE congeners); and the use, sale, offer for sale and import of those PBDEs that meet the criteria for virtual elimination under CEPA (tetraBDE, pentaBDE and hexaBDE congeners), as well as mixtures, polymers and resins containing these substances. In 2016, these regulatory controls were expanded under the Prohibition of Certain Toxic Substances Regulations, 2012, to include decaBDE and all products except manufactured items.

It is believed that all domestic producers in the United States voluntarily ceased production by 2013. However, PBDES may be still manufactured in small amounts.

Manufactured items containing PBDEs are still being imported into Canada and the United States and remain within in-use products and waste streams. PBDEs have been detected in sediment, air, wildlife, and fish and other biota in and around the Great Lakes and contribute to environmental degradation in the Great Lakes Basin.

There are a number of unknowns in both Canada and the United States concerning unquantified PBDE sources. No comprehensive registry of PBDE manufacturers, processors, or users of PBDE-containing products exists in either country. Additional monitoring is needed to acquire information on time series and scales that allow PBDE levels to be better known and modelled nationally, particularly in cases involving products or sources distributed in commerce. Policy gaps need to be filled; namely guidance is needed for importing, processing, and the use of manufactured items containing PBDEs and the waste management of those products. To address these challenges, this Binational Strategy document proposes multiple strategy options as outlined in **ES Table A**. By implementing the options presented in this Binational Strategy, stakeholders will be improving human and ecosystem health within the Great Lakes Basin and their respective communities.

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

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**
Strategic Options				
Issue regulations to reduce human and environmental exposure to decaBDE to the extent practicable, as directed by the amended Toxic Substances Control Act (US) Review current regulations in light of new scientific information (US) Update Canadian regulations to phase out remaining uses of PBDEs in manufactured items (Canada)	Conduct a comprehensive study of all regulatory mechanisms currently in place for PBDE control, management, enforcement, disposal, etc. (US) Enhance support to industry associations and firms who seek to phase out or improve risk management within their sector (US) Conduct surveys of recycling facilities and landfills to ascertain PBDE knowledge and compliance at these facilities and use the survey results to target facilities for further education (Canada and US)	Increase public outreach and educate the public and workers on potential sources of PBDE and proper actions to follow should PBDE-containing materials be found (US and Canada) Educate the public on safer alternatives and/or PBDE-free products (US) Encourage industries to use P2 activities and track their efforts in TRI databases (US) Highlight and share P2 successes (US) Enhance support to manufacturers who are seeking alternatives to brominated flame retardants, including PBDE (US) Research recycling program options, with a focus on determining how to incentivize the safe recycling of products containing PBDEs (US)	Continue to monitor PBDEs in environmental media in the Great Lakes (air, precipitation, sediment, fish, and other wildlife) and publish results in a variety of formats (e.g., on-line and open data portals, government reports, and scientific journals) to maximize the intended audience (Canada and US) Enhance existing monitoring activities by assessing the concentrations of PBDEs in air in remote, rural, and urban areas, as well as areas near hazardous waste sites and incinerators (Canada and US) Develop cost-effective tools for monitoring PBDE concentrations in all media from various sources (Canada and US) Develop structured data systems and plans for PBDE source, manifest, and product tracking (US) Develop models to track long-range atmospheric PBDE transport, deposition, and degradation pathways in the Great Lakes Basin (US) Continue to evaluate / assess risks associated with alternatives to PBDEs (Canada and US)	Obtain and analyze monitoring data on PBDE concentrations in drinking water and develop domestic water quality standards, if necessary (US)

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Acronyms and Abbreviations

AOC	Area of Concern
AMAP	Arctic Monitoring and Assessment Programme
ATSDR	Agency for Toxic Substances and Disease Registry
BDE	Bromodiphenyl Ether
CMC	Chemicals of Mutual Concern
CSMI	Cooperative Science and Monitoring Initiative
ECCC	Environment and Climate Change Canada
EEE	Electronics and Electrical Equipment
FEQG	Federal Environmental Quality Guideline
GAPS	Global Atmospheric Passive Sampling network
GC-MS	Gas Chromatography-Mass Spectrometry
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
IADN	Integrated Atmospheric Deposition Network
IARC	International Agency for Research on Cancer
ITT	Identification Task Team
LAMP	Lakewide Action and Management Plan
LRTAP	Long-Range Transboundary Air Pollution
MPO	Manufactured, Processed, or Otherwise Used
NABSB	National Aquatic Biological Specimen Bank
NCEA	National Center for Environmental Assessment
NPRI	National Pollutant Release Inventory
OMOECC	Ontario Ministry of Environment and Climate Change
P2	Pollution Prevention
PBB	Polybrominated Biphenyls
PBDE	Polybrominated Diphenyl Ether
PBT	Persistent, Bioaccumulative, and Toxic
PCB	Polychlorinated Biphenyl
POP	Persistent Organic Pollutants
REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
RoHS	Restriction of the Use of Certain Hazardous Substances
SiGL	Science in the Great Lakes
SNUR	Significant New Use Rule
SOLEC	State of the Lakes Ecosystem Conferences
SVHC	Substances of Very High Concern
TBB	Tetrabromobenzoate
TBPH	Tetrabromophthalate
TRI	Toxics Release Inventory
TSCA	Toxic Substances Control Act
US EPA	United States Environmental Protection Agency
US FDA	United States Food and Drug Administration
USGS	United States Geological Survey
WHO	World Health Organization
XRF	X-Ray Fluorescence

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 polybrominated diphenyl ethers (PBDEs) as one of eight CMCs. In designating PBDEs as a CMC, the Parties have agreed that they pose a threat to the Great Lakes, that current management actions are insufficient, and that further action addressing risks to the Great Lakes Basin is warranted. These actions are documented in binational strategies which 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 Governments of the United States and Canada are responsible for the implementation of the GLWQA. Within the United States, the United States Environmental Protection Agency's (US EPA) Great Lakes National Program Office (GLNPO) coordinates these efforts. Within Canada, Environment and Climate Change Canada's (ECCC) 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 PBDE strategy includes a list of 20 management options, in Canada and/or the United States, to address threats to water quality by reducing PBDE releases. These actions can be used to help identify, support or coordinate ongoing or new projects. The actions 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 PBDE as a CMC is available in the Binational Summary Report: Brominated Flame Retardants (PBDEs and HBCD) produced by the Identification Task Team (ITT) (2015). A final Action Plan for PBDE, has also been prepared by US EPA's Existing Chemicals Program under the authority of the Toxic Substances Control Act (TSCA).

2.1 Chemical Identity

PBDEs are a class of structurally similar and brominated hydrocarbons (or congeners) in which 2 to 10 bromine atoms are attached to the diphenyl ether molecule (

Figure 1). This structure makes theoretically possible 209 compounds or congeners for PBDEs. However, only a subset of the 209 theoretically possible congeners exists in commercial PBDE mixtures. PBDEs were sold commercially in 3 mixtures identified by their primary isomer or homolog, including pentabromodiphenyl ether (c-pentaBDE), octabromodiphenyl ether (c-octaBDE), and decabromodiphenyl ether (c-decaBDE)[1]. PBDEs are in the same brominated hydrocarbon class as polybrominated biphenyls (PBBs), another flame retardant, and possess very similar chemical and physical properties. PBBs were banned in the United States in 1976 following the exposure of millions of people to contaminated agricultural products. The United States Department of Health and Human Services has stated that, based on animal studies, PBBs are reasonably anticipated to be human carcinogens (US EPA, 2014b). PBBs were originally banned in Canada in 1979 (Polybrominated Biphenyl Regulations, SOR/79-351) and are currently prohibited under the Prohibition of Certain Toxic Substances Regulations, 2012, SOR/2012-285.

PBDEs are categorized by the degree of bromination, with the term "homolog" used to refer to all congeners of PBDEs with the same number of bromines. Commercial PBDE mixtures that were marketed and manufactured in the United States were composed primarily of three homologs: pentabromodiphenyl ethers (pentaBDE), octabromodiphenyl ethers (octaBDE), and decabromodiphenyl ethers (decaBDE) (La Guardia et al., 2006; ATSDR, 2017). Each commercial mixture has different commercial uses, and there are differences in the chemical properties and toxicities of each PBDE homolog (ITT, 2015).

2.2 Physical and Chemical Properties

Many physical and chemical properties of the PBDE commercial mixtures are listed in **Table 1**. PBDEs were manufactured and used as additive flame retardants in a wide variety of products, such as plastics, furniture, upholstery, electrical equipment, electronic devices, textiles, and other household products. The bromine atoms in PBDEs are highly capable of removing free electrons from other atoms, which are partially what drive the combustion process (Crimmins et al., 2012). PBDEs were added to products via physical mixing rather than chemical integration, leaving the possibility that the flame retardant may migrate out of the treated material and into the environment (ATSDR, 2017).

PBDEs are lipophilic and hydrophobic compounds, which make them more likely to bioaccumulate in terrestrial and aquatic food webs (ITT, 2015).

[1] c-pentaBDE was sold under the trade names Bromkal 70, Bromkal 70 DE, Bromkal 70 5DE, Bromkal G1, Great Lakes DE 71, Great Lakes DE-60F, FR 1205/1215, Pentabrompop, Saytex 115, and Tardex 50.
c-octaBDE was sold under the trade names DE-79, FR-1208, and Saytex 111. (UNEP 2005)

2.3 Environmental Fate, Transport, and Trends

Once released into the environment, PBDEs may be transported through the atmosphere (the primary means), water or via adsorption on suspended sediment. In the atmosphere, PBDEs exist in both the vapor and the particulate phase. Particulate-phase PBDEs can be removed from the atmosphere by wet and dry deposition. Gas-phase PBDEs can be removed by wet deposition (rain/snow scavenging) and air-surface exchange.

The discovery of PBDEs in polar ecosystems and in the tissue of ocean-dwelling mammals who are generally far removed from any anthropogenic sources of PBDEs indicates that the atmospheric transport of these compounds can occur over long distances (ITT, 2015). In water, PBDEs adsorb strongly to suspended solids and sediments from the water column, which can attenuate the volatilization of PBDEs from water to air.

Higher brominated PBDEs in soil are generally immobile, having very low likelihoods of leaching into groundwater and volatilizing into the atmosphere (ITT, 2015). Volatilization is more likely to occur in soil with low organic content (ATSDR, 2017). The more volatile lower brominated PBDEs, however, are better capable of volatilizing from soil to air. PBDEs are likely to be found in greater quantities in soil and sediment than in water and air (Environment Canada, 2011).

2.4 Sources and Releases of PBDEs in the Great Lakes

In the Great Lakes Basin, PBDE exposure and sources are largely anthropogenic and may come from Canadian and U.S. sources or global sources via long-range transport. House dust has been identified as a major PBDE exposure source, with 90% of the intake of adults and children (ages 1-19) being via house dust inhalation or dermal exposure (ATSDR, 2017).

2.4.1 Uses and Quantities in Commerce

The primary commercial production and import of PBDEs began in the United States in the late 1970s (ITT, 2015). Historical data on global PBDE production illustrate the magnitude of PBDE presence in products both still in use and those having gone through disposal processes. The US EPA (2010) estimated that 56,418 metric tons of PBDEs were produced worldwide in 2003 (the latest reporting year); between 40,000 and 67,000 metric tons were produced between 1999 and 2002. PBDEs were never manufactured in Canada, and the United States manufacturers voluntarily withdrew mixtures of PentaBDE and OctaBDE (2004) and almost all DecaBDE (2013) from the United States marketplace. However, despite the cessation of manufacturing of PBDEs and various international, national, and sub-national bans and restrictions (see Section 3), PBDE uses and PBDE-containing articles may remain in service. A substantial amount of PBDE-containing products in use, transport, storage, and disposal phases continues to contribute to PBDE releases in the Great Lakes Basin—and beyond.

Between 2011 and 2013, the Great Lakes Restoration Initiative (GLRI) funded the Great Lakes PBDE Reduction Project, which aimed to quantify the sources of PBDEs to the Great Lakes region and evaluate ways to track reductions (Abbasi et al., 2014).

Table 2 shows the quantities of PBDEs estimated in the Great Lakes region in 2004 (pentaBDE and octaBDE) and 2013 (decaBDE) and the products in which they are found. Abbasi et al. (2014) used x-ray fluorescence (XRF) gas chromatography-mass spectrometry (GC-MS) and sales and consumption data to estimate that approximately 40% of the PBDEs being used in the Great Lakes region in the peak usage year (2004) will still be in use in 2020.

2.4.2 Release Sources

The primary sources of PBDEs to the Great Lakes Basin are (ITT, 2015):

- Direct release(s) of PBDEs and PBDE-containing product(s)
- Release from the manufacture (including import), processing, and use of PBDEs and PBDE-containing products (e.g., plastics, textiles)
- Release from incineration, recycling, and/or disposal of products containing PBDEs, which can include such activities as landfill leachate discharging to surface water and volatilization from shredding of products for recycling
- Long-range atmospheric transport.

2.4.3 PBDEs in Environmental Media

There is ongoing monitoring in the Great Lakes Basin, some data exist and are summarized below. PBDE has been detected globally in various environmental media, with the highest concentrations of PBDE being found near urban and industrial areas.

Figure 2 shows the trend in total pounds of decaBDE reported released to the environment since 1998. The US Toxics Release Inventory (TRI) program tracks the release of certain chemicals that may pose a threat to human health and the environment. Annual release and management data are submitted by industrial facilities, and the information is shared with the public to facilitate effective decision-making and to elucidate trends. The TRI has been tracking the release of decaBDE since 1988. The following sections include TRI data specific to types of releases, as well as any available additional release information.

2.4.3.1 In Air

According to the Toxics Release Inventory (TRI), an estimated 1,003 pounds of decaBDE were released to the atmosphere from United States manufacturing and processing facilities in 2016 (US EPA, 2017b); no TRI data were available for pentaBDE or octaBDE. TRI data from 1998 to 2016 plotted in **Figure 3** reveal a rapidly decreasing trend in atmospheric release of decaBDE.

The Great Lakes Integrated Atmospheric Deposition Network (IADN) and Environment and Climate Change Canada's Chemicals Management Plan Monitoring and Surveillance in the Great Lakes Basin (GLB) program form a collaborative binational monitoring network that has been in operation since 1990. IADN uses a network of stations that monitor a suite of persistent toxic chemicals in precipitation and air. IADN measures a suite of 36 individual PBDE congeners (**Table 3**). Of these 36 congeners, the most important and abundant are BDE 47, 99, 100, 153, 154, 183 and 209. Results from air and precipitation samples collected every 12 days at five sites near the North American Great Lakes from 2005 to 2011 show that the decline in the environment of PBDEs correlated with the phase-out of penta- and octa-PBDE (IJC, 2016). IADN is a long-term monitoring program run by the U.S. Environmental Protection Agency's Great Lakes National Program Office.

PBDEs have been monitored by IADN and GLB since 2005. The atmospheric concentrations of PBDEs are highest in samples collected near urban centers, such as Cleveland, Chicago, and Buffalo (**Figure 4**). As reported by Liu et al. (2016), the concentrations of PBDEs are generally decreasing with time at the urban sites (Chicago and Cleveland) but were generally unchanging at the remote sites (Sleeping Bear Dunes and Eagle Harbor). Decreasing PBDE concentrations with time were also observed at two Canadian Great Lakes sites (Lakes Ontario and Huron) (**Figure 5**). As reported by Shunthirasingham et al.

(2018), the decline in concentrations at the Lake Ontario site (Point Petre), which is closer to an urban center, was faster than at the site near Lake Huron (Burnt Island).

Canada's National Pollutant Release Inventory (NPRI) requires certain facilities that meet the requirements to report releases, disposals, and transfers for recycling of decaBDE. This substance was previously imported into Canada for industrial use. In 2015, one facility reported releasing 25.3 kg of decaBDE (media unspecified). There were no disposals or transfers for recycling reported to the NPRI for 2015. In recent years, decaBDE emissions have declined in response to Canadian regulatory controls and the phase-out of decaBDE manufacturing that occurred in the United States.

Canadian air monitoring data collected by ECCC show that PBDEs appear in higher concentrations near urban centers, with 157 pg/m^3 detected in Hamilton, Nova Scotia and similar levels found in Edmonton, Alberta, and Toronto, Ontario. Much lower concentrations (7 pg/m^3) were observed in the more remote location of Alert, Nunavut (Environment Canada, 2011). Under the international Arctic Monitoring and Assessment Programme (AMAP), long-term air monitoring has been conducted since the 1990s using high volume samplers in Canada and other Arctic nations. At the sampling station in Alert, Nunavut, Canada, BDE 47 (tetraBDE) has been measured since 2002. Results show that concentrations have been mostly unchanging since that time. At European AMAP sites (in Finland, Norway, and Iceland), air concentrations of BDE 47 showed significant declining trends. It is suspected that the stable concentrations at Alert are influenced by the presence of Canadian Forces Station Alert, a military base that contains PBDE-treated items, or the generally much higher historical usage of PBDEs in North America (Hung et al., 2016).

Global data on PBDEs and replacement chemicals is provided by the Global Atmospheric Passive Sampling (GAPS) network where PBDEs have been monitored in air in since 2005 at more than 60 sites (Rauert et al., ES&T, 2018). The regional and global context for PBDEs and their long-range transport is also provided under the Global Monitoring Report for the Stockholm Convention on POPs (Harner et al., 2015).

2.4.3.2 In Surface Water

PBDEs can enter surface water via manufacturing effluent, wastewater effluent, or landfill leachate. According to TRI data from 2016, approximately 5 pounds of decaBDE were released to surface water from United States manufacturing and processing facilities; however, TRI data are not exhaustive because only certain types of facilities are required to report their releases. As shown in **Figure 6**, TRI data from 1998 to 2016 reveal a rapidly decreasing trend in surface water releases of decaBDE (US EPA, 2017b).

Results from recent work conducted on each of the Great Lakes for PBDEs showed higher concentrations in the lower Great Lakes and the spatial patterns were consistent with consumer products as a primary source (ECCC and US EPA, 2017)). A study of PBDEs in air, tributaries, and Wastewater Treatment Plant (WWTP) effluent in the Toronto area by Ontario Ministry of Environment and Climate Change (MOECC), ECCC and the University of Toronto (Melymuk et al. 2014) found that loadings to Lake Ontario were dominated by tributaries (48%) and WWTPs (42%). The study suggested that opportunities for source reduction lie in reducing the current inventories of in-use PBDE-containing products.

2.4.3.3 In Sediments

Sources such as effluent, atmospheric deposition, and releases from disposal units can lead PBDEs to accumulate in sediment. Between 2009–2010 and 2013–2014, ECCC sampled and analyzed sediment concentrations of pentaBDE, octaBDE, and decaBDE. The Great Lakes drainage area (in addition to other regions in Canada) was shown to have pentaBDE concentrations above the Canadian Federal Environmental Quality Guideline (FEQG). However, the concentrations of octaBDE and decaBDE in the Great Lakes region were below the FEQG, and decaBDE concentrations in that region appear to have declined between 2007 and 2011 (ECCC, 2017). The Lake Ontario BDE profile indicates a leveling off of accumulation in the past decade, presumably as a result of voluntary cessation of production of these compounds in North America. However, other contemporary studies have shown total PBDEs, and in particular the deca-substituted BDE 209 are continuing to increase across all five Great Lakes, with doubling times ranging from 4 years to 74 years (ECCC and US EPA, 2017).

According to TRI data from 2016, approximately 95 tonnes (207,820 pounds) of decaBDE were released to landfills and surface impoundments from United States manufacturing and processing facilities, but these data are not exhaustive because only certain types of facilities are required to report their releases. As shown in **Figure 7**, TRI data from 1998 to 2016 reveal a decreasing trend in landfill and impoundment releases of decaBDE, with a recent sharp increase (US EPA, 2017b).

2.4.3.4 In Biota

PBDE concentrations in top predatory fish have been measured by US EPA's Great Lakes Fish Monitoring and Surveillance Program. The data show concentrations of PBDEs in Lake Trout and Walleye rose continuously through to the early 2000s, and then began to decline (ECCC and US EPA, 2017). As part of the 2010 National Coastal Condition Assessment (NCCA), US EPA conducted the first human health-related study to provide statistically based data on toxic chemicals in Great Lakes fish. For this Great Lakes Human Health Fish Tissue Study (GLHHFTS), US EPA collected samples of fish commonly consumed by humans at 157 of the statistically representative 225 Great Lakes nearshore sampling locations (about 30 fish samples per lake) and analyzed the skin on fillet (muscle) tissue for toxic chemicals, including PBDEs. While PBDEs were detected in all 157 samples, less than 1% of the Great Lakes nearshore area sampled (or 4,282 square miles) exceeded the 210 ppb human health screening value for PBDEs (US EPA, 2016d).

As part of the Great Lakes Fish Contaminant Monitoring and Surveillance Program, ECCC has conducted annual measurements of PBDEs in top predatory fish in 11 drainage regions all over Canada since 2005. The monitoring covers 12 locations in the Great Lakes. Using preserved specimens from the National Aquatic Biological Specimen Bank (NABSB), concentrations in fish in Lake Ontario were determined back to 1997. While the most recently available data (2012) indicate all lake trout and walleye collected from the Great Lakes drainage area returned a concentration reading above the FEQG for pentaBDE, 1.0 ng/g wet weight, the overall trend from 1997 to 2012 shows a distinct decline in pentaBDE concentrations in Lake Ontario lake trout, about 4.5% per year (**Figure 8**) (ECCC, 2017). Similar rates of decline were also seen for tetra- and hexa-BDEs in lake trout from Lake Ontario.

A study by MOECC and University of Windsor (Gandhi et al. 2017) measured PBDEs in edible portions of Great Lakes fish, with the goal of examining patterns/trends and evaluating implications for human exposure. Bottom dwelling common carp (and white sucker) exhibited the highest ∑PBDE levels (27-71 ng/g). Lake trout and lake whitefish from Lake Superior had higher levels than those from the other Great Lakes; otherwise the spatial trend was for Lake Ontario to have the highest levels. Results showed that consumption restrictions would only be required for common carp in the Toronto waterfront area, which is in proximity to the most urbanized region on the Canadian side of the basin. Deca-BDE was the major congener in panfish, while the BDE-47 congener was the major congener in top predators and its contribution to ∑PBDE increased with the contamination. Levels of major lower brominated PBDEs appear to have declined in fish fillets by 46-74% between 2006/07 and 2012. The study concluded that although PBDE in existing consumer items will remain in-use for a while, it will likely not result in appreciable accumulation of PBDEs in fish. Based on this overall assessment, the authors state that regular monitoring of PBDEs in Great Lake fish can be replaced with targeted surveillance and focus can be shifted to other in-use flame retardants.

Temporal trends (1982 to 2006) of ΣPBDEs in Herring Gull egg pools from 6 colonies in the Great Lakes, congeners derived mainly from Penta-BDE and Octa-BDE formulations (e.g., BDE-47, -99 and -100), showed rapid increases up until 2000, but with no further increasing trend from 2000 to 2006 (Gauthier et al. 2008). In a more recent study (Su et al. 2015), ΣPBDE concentrations in eggs collected in 2012 from the same 6 sites were generally less than those collected in 2006. The mean ΣPBDE concentration of 425 ng/g wet weight across the 6 colonies in 2012 was 33% less than the 629 ng/g wet weight measured as the mean across the same 6 colonies in 2006. However, gull egg pools from the 2012 collections had greater concentrations of BDE-209 compared to egg pools from previous collections for these 6 colonies. In eggs collected in 2006, BDE-209 concentrations ranged from 4.5 to 20 ng/g wet weight (Gauthier et al., 2008) whereas in Su et al. (2015) they ranged from 7.46 to 51.2 ng/g wet weight in eggs collected in 2012.

2.5 High Level Summary of Risks

The primary route of exposure to PBDEs in the United States is through ingestion of contaminated dust in indoor environments and, to a lesser degree, skin exposure to that dust. These exposure routes account for 80 to 90% of human exposure in the United States, while the remaining 10 to 20% of exposure comes from ingestion of contaminated foods, including fatty fish and breast milk. EPA's National Center for Environmental Assessment (NCEA) calculated the adult intake dose of total PBDEs to be 7.1 ng/kg body weight/day. It estimated children's intakes as 47.2 ng/kg body weight/day for 1- to 5-year-olds, 13.0 ng/kg body weight/day for 6- to 11-year-olds, and 8.3 ng/kg body weight/day for 12- to 19-year-olds (US EPA, 2010). The much higher dose for children aged 1 to 5 years was largely due to higher soil/dust ingestion in this age group. Drinking water is not a major exposure route for PBDEs because the compounds bind so strongly to sediment and soil (ATSDR, 2017).

Rodent studies have indicated that the primary health effects associated with PBDE exposure include neurodevelopmental toxicity, weight loss, kidney toxicity, thyroid, liver, and dermal disorders, which may have implications for human health. There is evidence that PBDEs act as endocrine disruptors and deposit in human adipose tissue (IJC, 2016).

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

3.1 United States

3.1.1 Existing Statutes and Regulations

In 2006, two years after the voluntary phase-out of pentaBDE and octaBDE, the US EPA announced a complementary Significant New Use Rule (SNUR) (74 FR 34015) for PBDEs. The SNUR required anyone who intended to manufacture or import a chemical or mixture containing pentaBDE or octaBDE to notify US EPA at least 90 days in advance. This advance notice allows the US EPA to assess the intended use of the chemical or mixture to determine if it needs to be limited or prohibited.

In 2012, the US EPA announced a proposal to amend the SNUR to include other significant new uses: (1) the processing of any combination of the pentaBDE and octaBDE congeners; (2) the manufacturing, import, or processing of decaBDE; and (3) the manufacturing, importing, or processing of any article to which PBDEs had been added. The US EPA simultaneously proposed a TSCA test rule for pentaBDE, octaBDE, and decaBDE, which would require the development of information to determine the health and environmental effects of manufacturing, processing, or other activities involving these three PBDE mixtures. The test rule was to be promulgated only if the manufacturing, importing, and/or processing of these PBDE mixtures had not ceased by December 31, 2013 (US EPA, 2017a). However, to date, neither rule has been finalized. There is no explicit prohibition of decaBDE, other penta- and octa-BDE congeners, or PBDE-containing products however, no chemical manufacturer has reported manufacturing or importing PBDEs in quantities greater than 25,000 pounds (11.3 tonnes) in the United States since 2015.

In 2016, the US EPA announced that it was expediting action to reduce exposure to five persistent, bioaccumulative, and toxic (PBT) chemicals, one of which was decaBDE. The TSCA was amended in 2016 by the Frank R. Lautenberg Chemical Safety Act, which included a requirement for the US EPA to evaluate the risk of PBT chemicals with clear and enforceable decision deadlines and for new chemicals to undergo a safety evaluation before they could enter the market. Consistent with the new TSCA mandate on PBTs, the US EPA is conducting a use and exposure assessment on these five chemicals. If the US EPA determines that human or environmental exposure to one or more of these chemicals is likely, the US EPA will issue regulations to reduce exposure to the extent practicable.

Of the states surrounding the Great Lakes, Illinois, Michigan, Minnesota, and New York have established bans on the manufacturing, processing, or distribution of products or the flame-retardant part of a product containing more than 0.1% of pentaBDE and octaBDE. Michigan and Minnesota exempt carpet pads and used vehicles from this ban. Beginning on July 1, 2018 Minnesota's law will ban the manufacture or importation of furniture, upholstery, and children's products containing anything exceeding 0.1% of decaBDE. Additionally, a ban on the sale of such products in Minnesota will take effect on July 1, 2019. Three of the states surrounding the Great Lakes (Pennsylvania, Ohio, and Wisconsin) do not have state regulations for PBDEs; however, Pennsylvania and Wisconsin have mandatory electronics recycling laws and prohibitions on landfill or incineration disposal of electronics (IJC, 2016), which prevents PBDEs found in electronics from entering the environment from that source and in that manner.

States outside the Great Lakes region also regulate PBDEs (California, Hawaii, Maine, Maryland, Rhode Island, Oregon, and Washington). In 2008, California began banning the manufacture, processing, or distribution of products or the flame-retardant part of a product containing more than 0.1% of pentaBDE and octaBDE. Also in 2008, the Washington state legislature prohibited the manufacture, sale, and distribution of products containing PBDEs, with some exceptions for transportation equipment, medical devices, and some recycled materials. Washington also prohibits decaBDE in mattresses, televisions, computers, and residential upholstered furniture (Washington State Department of Health, 2017).

3.1.2 Pollution Prevention Actions

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 with the accumulation of PBDE data in TRI and flame-retardant alternatives research, P2 programs involving PBDEs will come into effect in the future.

3.1.2.1 Alternatives to PBDEs

As part of US EPA's PBDEs Action Plan (2009), US EPA's Design for the Environment program was tasked with identifying and comparing potential alternative flame-retardant substances to decaBDE in terms of human health and environmental risk. In January 29, 2014, the US EPA released the final An Alternatives Assessment for the Flame Retardant Decabromodiphenyl Ether (DecaBDE), in which 29 potentially functional and viable alternatives to decaBDE were evaluated (US EPA, 2014a). The study examined three main types of flame retardant: halogenated (including brominated compounds), phosphorus/nitrogen-based, and inorganic.

However, some alternatives to PBDEs have already begun to be detected in environmental samples. Atmospheric concentrations of tetrabromobenzoate (TBB) and tetrabromophthalate (TBPH) have been increasing in the Great Lakes area, another alternative (tetrabromobisphenol-A) has been identified as bioaccumulating in the Herring Gull food chain, and other brominated and organophosphate ester flame retardants have been detected in Great Lakes water (Liu et al., 2016). Shunthirasingham et al. (2018) also found that emerging halogenated flame retardants (HFRs) allyl 2,4,6-tribromophenyl ether (TBP-AE), hexabromobenzene (HBBz), pentabromotoluene (PBT), anti-dechlorane plus (anti-DDC-CO) and syn-dechlorane plus (syn-DDC-CO) were frequently detected in air in the GLB. The levels of syn-DDC-CO and anti-DDC-CO are decreasing at Point Petre and the levels of other non-PBDE HFRs such as TBP-AE, PBT and HBBz are increasing.

The toxicity of most alternative flame retardants to PBDEs is unknown (IJC, 2015a). The issue and challenges associated with replacement chemicals for PBDEs and their potential to behave like POPs has been raised at the global scale under the Stockholm Convention on POPs (Harner et al., 2015; Daniel et al., 2018).

3.1.3 Risk Management Actions

The Great Lakes Restoration Initiative (GLRI) is a United States initiative launched in 2010 that provides funds for accelerating 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 over 4 million cubic yards (3 million cubic meters) of contaminated sediment (US EPA, 2016a).

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) and in IADN Data Viz. 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 these systems for users of Great Lakes data (US EPA, 2016b). Science in the Great Lakes (SiGL) Mapper is an additional meta data mapping 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, water, tissues). These long-term programs are focused on the tracking of trends of environmental pollutants across the basin to assess environmental health, including PBDEs.

Additionally, GLNPO supports work on toxic chemicals, including PBDE, with other partners via grants, interagency agreements, and collaborations to address chemical issues, as they relate to human health. The reporting of results from GLNPO programs and projects is conducted through a variety of mechanisms, including the State of the Lakes Reports, LAMPs, and peer-reviewed literature. Data are made public via US EPA websites and databases, such as GLENDA and IADN Data Viz.

3.1.5 United States Guidelines and Standards

The United States has several standards and guidelines regarding levels of PBDEs in air, for ingestion, and oral exposure (**Table 4**).

3.2 Canada

Although PBDEs were never manufactured in Canada, they were widely imported as commercial mixtures and were added to a variety of products sold and used in Canada.

3.2.1 Federal Risk Management Measures

To prevent the manufacture of PBDEs in Canada and to significantly restrict their use, the Government of Canada published the *Polybrominated Diphenyl Ethers Regulations* (SOR/ 2008-218) in 2008. These regulations prohibited the manufacture in Canada of tetraBDE, pentaBDE, hexaBDE, heptaBDE, octaBDE, nonaBDE, and decaBDE. In addition, the use, sale, offer for sale, and import of tetraBDE, pentaBDE and hexaBDE and mixtures, polymers and resins containing them were also prohibited.

The *Regulations Amending the Prohibition of Certain Toxic Substances Regulations, 2012*, include further controls on PBDEs (ECCC, 2016). The Amendments expand the prohibition to all PBDEs (including decaBDE) and products containing them, except manufactured items. The original *Polybrominated Diphenyl Ethers Regulations* were repealed when the Amendments came into force on December 23rd, 2016.

Canada played an active role in the process of adding pentaBDE, octaBDE (2009), and decaBDE (2017) to the Stockholm Convention, as well as pentaBDE and octaBDE to the Persistent Organic Pollutant (POPs) Protocol of the United Nations Convention on Long-range Transboundary Air Pollution (LRTAP). These PBDEs have been added to these conventions because they can be transported long range, are persistent and bioaccumulative, and are likely to cause adverse effects as a result of their long-range transport (Environment Canada, 2010).

3.2.2 Pollution Prevention Actions

At this time, the Government of Canada is building its knowledge on end-of-life management practices addressing various substances 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.

3.2.3 Monitoring, Surveillance and other Research Efforts

ECCC conducts monitoring for PBDEs in air, fish, Herring Gull and European starling eggs and other sentinel wildlife species, sediment and water under several different initiatives, including the Chemicals Management Plan. As part of ongoing Great Lakes program activity both ECCC and MOECC conduct in-depth assessment of surface waters, surface sediments, and sediment cores on a rotational basis from one Great Lake annually. Additional water and sediment samples are also collected from the connecting channels of the annually assessed lake. This annual assessment incorporates a wide range of contaminants and will include PBDEs at selected locations in selected media.

Results are published widely, including government reports (e.g., Polybrominated diphenyl ethers in the Canadian Environment), peer-reviewed articles (e.g., articles referenced in the ITT), and GLB data is available on the ECCC Open Government Portal.

NPRI, Canada's Pollutant Release and Transfer Registry, has tracked industrial releases, disposals, and transfers of decaBDE CAS RN# 1163-19-5 from industrial sources since the NPRI program's inception in 1993. More specifically, facilities are required to annually report their releases, disposals, and transfers for recycling of decaBDE to the NPRI if they met the following reporting criteria:

- The facility has the equivalent of 10 or more full-time employees
- They manufactured, processed, or otherwise used (MPO) 10 or more tonnes of decaBDE at a concentration of at least 1% concentration by weight.

3.2.4 Canadian Environmental Quality Guidelines and Standards

Canadian federal and provincial environmental quality guidelines for PBDEs have been developed by Environment and Climate Change Canada and the Ontario Ministry of Environment and Climate Change (OMOECC), respectively.

Federal Environmental Quality Guidelines (FEQGs) have been developed in Canada for certain congeners of PBDEs in water, fish tissue, sediment, wildlife (fish and bird eggs) to assess the ecological significance of levels of PBDEs in the environment. These FEQGs are benchmarks for aquatic ecosystems that are intended to protect all forms of aquatic life (vertebrates, invertebrates, and plants) from direct adverse effects. The FEQGs for PBDEs are presented in **Table 5**. Where the FEQG is met, there is low potential of adverse effects on the protected uses (e.g., aquatic life or the wildlife that consume them). The use of FEQGs is voluntary unless prescribed in permits or other regulatory tools.

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, 2016c). CMCs will be considered as future priority for monitoring in the Lake Superior LAMP program (Lake Superior Partnership, 2016). Other LAMPs are in the process of reviewing their monitoring priorities, and will consider CMCs in the future.

3.3.2 US's Integrated Atmospheric Deposition Network (IADN) and Canada's Monitoring and Surveillance in the Great Lakes Basin (GLB) Program

Long-term atmospheric monitoring stations on the shores of the Great Lakes region in the US and Canada have been in operation since 1990. The Integrated Atmospheric Deposition Network (IADN) was established in 1990 as a joint effort between Canada and the US in support of the Great Lakes Water

Quality Agreement. Canada's Monitoring and Surveillance in the GLB under the Chemicals Management Plan contributes measurement data to this joint effort. The programs are managed by US EPA and ECCC respectively.

The goals of IADN and GLB are to (i) determine the spatial and temporal trends of toxic chemicals in Great Lakes air; (ii) estimate the atmospheric loadings of the toxic chemicals to the Great Lakes; and (iii) identify sources and/or source regions. The programs are also used to discover new emerging chemical threats to the Great Lakes.

The IADN and GLB programs are continually developing methods for new and emerging compounds of interest. Methods for polybrominated diphenyl ethers (PBDEs) have been successfully implemented since their addition to the list of routinely monitored analytes in 2005. IADN data is publicly available on IADN Data Viz and GLB data is available on ECCC's Open Government Portal.

3.3.3 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 Canadian/United States 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. 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 Wide Partnerships identify science needs according to the CSMI schedule, and the Task Team implements these recommendations, as appropriate.

3.4 International

Several frameworks have been established at the international level to limit the availability, use, discharge, and overall number of PBDE sources.

3.4.1 United Nations Environment Program: Stockholm and Basel Conventions

The Conference of the Parties (COP) to the Stockholm Convention on Persistent Organic Pollutants decided at its fourth meeting, in 2009, to list tetraBDE, pentaBDE, hexaBDE and heptaBDE to Annex A with specific exemptions. In addition, at its eighth meeting, in 2017, the COP decided to list decaBDE to 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 U.S the Convention has not yet entered into force. Canada ratified the listing of tetraBDE, pentaBDE, hexaBDE and heptaBDE in April 2011 and meets these obligations through the PCTSR.

A key activity under the Stockholm Convention on POPs is the Global Monitoring Plan that reports POPs in core media (air and human milk/blood) on a 6-year cycle. These data provide global context for interpreting PBDE spatial and temporal trends and inform on the effectiveness of implemented control measures on PBDEs (Daniel et al., 2018).

While the Stockholm Convention is concerned with controlling the production and use of POPs, the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal is focused on the management of POPs when they become waste. Parties to the Basel Convention are responsible for ensuring that transboundary movement of hazardous and other wastes, such as PBDEs, are minimized, and are required to give notice of movements and ensure environmentally responsible disposal. Canada signed and ratified the Basel Convention in 1992. The United States signed the Convention in 1990, but has not yet ratified it. Under the Basel Convention, technical guidelines have been developed for the environmentally sound management of wastes consisting of, containing, or contaminated with PBDEs. Technical guidelines provide for the foundation upon which countries can operate at a standard that is not less environmentally sound than that required by the Basel Convention. (Basel Convention, 2017)

3.4.2 European Directive on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment

The Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) Directive in the European Union aims to restrict several hazardous chemicals from waste electronics and electrical equipment (EEE), including PBDEs. The Directive mandates that there must be no more than 0.1% PBDEs (by weight) in EEE, and EEE producers must demonstrate compliance via technical documentation, which should include conceptual design and manufacturing drawings, technical specifications, and testing reports (IJC, 2015b).

3.4.3 European Commission: Registration, Evaluation, Authorization and Restriction of Chemicals Regulation

The Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) regulation obliges all chemical manufacturers who produce more than one metric ton annually to provide technical documentation on the properties of the chemical as well as the risks it poses. For those chemicals deemed “substances of very high concern (SVHC),” which includes decaBDE, the manufacturers must obtain authorization for each use, demonstrate risk management measures, and prove that the socioeconomic benefit of the chemical outweighs the risks.

3.4.4 Commission Regulation (EU) No 757/2010 of 24 August 2010 amending Regulation (EC) No 850/2004 of the European Parliament and of the Council on persistent organic pollutants as regards Annexes I and II

For tetraBDE, pentaBDE, hexaBDE and heptaBDE substances, an exemption from the control measures apply in the EU when they are present in less than or equal to 10 ppm in substances, preparations, articles or as a constituent of flame retarded parts of articles. If an article or preparation is made from recycled materials, materials prepared from waste, the limit is 1000 ppm. There is also an exemption for electrical and electronic equipment within the scope of Directive 2002/95/EC. For decaBDE and octaBDE, the concentration limit is 0.1 % by weight.

4 Gap Analysis

As part of a review of PBDEs under Annex 3 of the Great Lakes Water Quality Agreement, the CMC ITT recommended: (1) continuing to monitor air, sediment, top-predatory fish, and Herring Gull and European starling eggs for the purpose of understanding long-term trends, protecting human health through provision of fish consumption advisories, and evaluating atmospheric transport and loadings to the Great Lakes; and (2) further research on the effects of the degradation byproducts of PBDEs (i.e., lower brominated BDE-congeners), in particular for the long term. This draft report, issued in September 2015, notes that “more data on temporal trends of PBDE and HBCD concentrations in a variety of matrices and locations are needed before the current status of these compounds can be fully assessed, and the impact of regulation and changing usage patterns among different flame retardants determined" (ITT, 2015).

There are a number of unknowns in both Canada and the United States concerning unquantified PBDE sources. No comprehensive registry of PBDE manufacturers, processors, or users or PBDE-containing products exists in either country. Furthermore, no reference or tool identifies which products manufactured in or imported to the Great Lakes region contain PBDEs and the levels contained in each product. Understanding the number of products containing PBDE in the Great Lakes region would not only help manage potential risks from activities involving PBDEs or PBDE-containing products, but also help stakeholders make more informed product purchasing choices.

Although PBDEs are no longer knowingly manufactured in the United States and have never been manufactured in Canada, some countries continue to manufacture PBDEs and incorporate PBDEs into other products (e.g., articles), and long-range transport is a likely continued source of PBDE to the Great Lakes Basin. To better understand residual risks, additional monitoring of PBDEs and the alternative brominated flame retardant products taking their place in environmental media is needed not only in the Great Lakes Basin, but also in areas with the potential to affect the Great Lakes Basin (e.g., the remainder of state areas not in the basin, transporters through the basin, etc.), nationally and globally. Additional monitoring should acquire information on time series and scales that allow PBDEs 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.

In addition to the monitoring needs, there are policy gaps that need to be filled, namely clarifications are needed regarding the importing, processing and use of products containing PBDEs and the waste management of those products. Recent biota and sediment studies in the Great Lakes region have indicated that concentrations of some PBDE congeners are declining (ECCC, 2017). However, more research is necessary on the various options and the pros and cons for controlling or restricting the importation of products containing PBDEs, how such restrictions would be enforced, and how to gain firmer control over the end-of-life waste management of products containing PBDEs (recycling, disposal, and monitoring). Understanding the costs and benefits of recycling PBDE products could help develop economic incentives for disposing of these products in an environmentally safe manner. As part of this research, green design opportunities that avoid the need for flame retardants should also be considered.

Furthermore, there is a need to ensure that chemical data collected by federal, state, provincial, Tribal, First Nations, Métis, and other government programs are consistent, standardized, and structured to allow for improved binational monitoring for PBDEs and PBDE-containing products, as well as alternative chemicals and products with similar such risks. Working to ensure uniformity of data can be helpful in guaranteeing that independent data collection actions can be used collectively to address and identify PBDE 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 PBDE. Some areas that have been identified include:

- *Releases from Products in Use.* This would include PBDE releases from:
    - Products containing foams (e.g., insulation materials, furniture, car seats)
    - Carpet padding
    - Textile coatings, drapes, curtains, fabric blinds and roller blinds
    - Clothing

  - Mattresses and pillows
  - Large and small appliances
  - Waste electronics and electrical equipment
  - Construction, renovation, and demolition materials
- *Releases from Waste Products*. There is a gap in understanding the extent to which PBDE will be released in waste streams (e.g., landfilled wastes, incinerators).
- *Monitoring Needs*. There is a need to initiate/continue activities to monitor long-term trends in water, air, sediment, and biota (top-predatory 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 to assist importers and users of finished products on the United States disclosure requirements (e.g. State level) for the PBDE content of finished products.
- *PBDE Product Testing*. Testing is required to determine the concentration of PBDEs in products that are being imported.

5 Risk Mitigation and Management Options to Address Gaps

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

5.1 Regulations and Other Risk Mitigation and Management Actions

PBDEs were never manufactured in Canada and are no longer known to be manufactured (but may be imported) in the United States due to a voluntary industry phase-out by major PBDE manufacturers. In Canada, PBDEs are managed under the *Prohibition of Certain Toxic Substances Regulations, 2012*. As mentioned above, the regulations prohibit all PBDEs substances and products containing them, except manufactured items. ECCC is currently evaluating approaches for managing any risks associated with manufactured items containing PBDEs which are not currently prohibited. In the United States, any manufacture or import of certain pentaBDE and octaBDE chemical substances for a significant new use requires EPA notification under the PBDE SNUR; however, this SNUR does not include decaBDE, all congeners of penta- and octa-BDE, or PBDE-containing products known as articles. Thus, continued PBDE use is not prohibited.

FEQGs have been established in Canada as benchmarks for environmental PBDE concentrations. Some environmental standards have been established in the United States. However, PBDEs are not currently covered under the Clean Air Act or the Clean Water Act. Efforts should be made to evaluate the human health and environmental risk profile of PBDEs and determine whether additional coverage under other regulations would be helpful.

Summary of Regulations and Other Risk Mitigation and Management Strategy Options

- Issue regulations to reduce human and environmental exposure to decaBDE to the extent practicable, as directed by the amended Toxic Substances Control Act (US)
- Review current regulations in light of new scientific information (US)
- Update Canadian regulations to phase out remaining uses of PBDEs in manufactured items (Canada)

5.2 Compliance Promotion and Enforcement

Critical to the management of PBDEs in the Great Lakes environment is a comprehensive understanding of current federal and state regulations, how those regulations are developed and implemented, how they can work in concert with one another, and how jurisdictions can provide compliance and enforcement support to one another.

Summary of Compliance Promotion and Enforcement Strategy Options

- Conduct a comprehensive study of all regulatory mechanisms currently in place for PBDE control, management, enforcement, disposal, etc. (US)
- Enhance support to industry associations and firms who seek to phase out or improve risk management within their sector (US)
- Develop structured data systems and plans for PBDE source, manifest, and product tracking (US)
- Conduct surveys of recycling facilities and landfills to ascertain PBDE knowledge and compliance at these facilities and use the survey results to target facilities for further education (Canada and US)

5.3 Pollution Prevention

User-friendly documents would be beneficial for educating and engaging the public in efforts to reduce the potential for PBDE release or exposure and present safer alternative and/or PBDE-free products to use. Such documentation may help prevent low-level PBDE pollution from being incorporated into general solid waste streams, and provide awareness of potential PBDE sources.

EPA's TRI and Canada's NPRI databases can be used to track industrial progress in reducing waste generation. The TRI database should be maintained and leveraged to maximize pollution prevention (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 PBDE 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 workers on potential sources of PBDE and proper actions to follow should PBDE-containing materials be found (US and Canada)
- Educate the public on safer alternatives and/or PBDE-free products (US)
- Encourage industries to use P2 activities and track their efforts in TRI databases (US)
- Highlight and share P2 successes (US)
- Enhance support to manufacturers who are seeking alternatives to brominated flame retardants, including PBDE (US)
- Research recycling program options, with a focus on determining how to incentivize the safe recycling of products containing PBDEs (US)

5.4 Monitoring, Surveillance, and Other Research Efforts

Existing research does not present a complete understanding of the status and trends of PBDE in the Great Lakes environment. 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-predatory fish and Herring Gull eggs and tissue or eggs of other terrestrial consuming birds such as European starlings]) in the Great Lakes region.

The State of the Lakes Assessments assists the Parties to identify current, new and emerging challenges to Great Lakes water quality and ecosystem health. Assessments also help Governments to evaluate the effectiveness of programs and policies in place to address challenges, and help inform and engage others (ECCC and US EPA, 2017). The addition of PBDE as a CMC may increase future PBDE-focused initiatives. The continuation of such efforts by the two nations will be invaluable for understanding the overall status of PBDE 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 PBDE concentrations from a variety of sources is essential. Continuing application of passive sampling for monitoring PBDE levels in aquatic environments can be used to better understand the spatial distribution and behavior of PBDE in the Great Lakes, and the region as a whole. Should environmental sampling indicate that localized hot spots are causing excessive exposure to aquatic biota, source tracking PBDE contamination may be a need in the future. Efforts such as Project Trackdown, which uses a multimedia weight-of-evidence approach for tracing polychlorinated biphenyl (PCB) sources in the Great Lakes, may be a model system for future PBDE studies (Benoit et al. 2016). In addition, future monitoring efforts should be designed such that the resultant data can be compared among research teams and to historical data. Newly developed sampling methods could be verified by the Parties, through another testing organization, or through a field study/demonstration to increase the perceived confidence in the resultant data.

Summary of Monitoring, Surveillance, and Other Research Options

- Continue to monitor PBDEs in environmental media in the Great Lakes (air, precipitation, sediment, fish, and other wildlife) and publish results in a variety of formats (e.g., on-line and open data portals, government reports, and scientific journals) to maximize the intended audience (Canada and US)
- Enhance existing monitoring activities by assessing the concentrations of PBDEs in air in remote, rural, and urban areas, as well as areas near hazardous waste sites and incinerators (Canada and US)
- Develop cost-effective tools for monitoring PBDE concentrations in all media from various sources (Canada and US)
- Develop structured data systems and plans for PBDE source, manifest, and product tracking (US)
- Develop models to track long-range atmospheric PBDE transport, deposition, and degradation pathways in the Great Lakes Basin (US)
- Continue to evaluate / assess risks associated with alternatives to PBDEs (Canada and US)

5.5 Domestic Water Quality

Domestic waters include all water used for indoor and outdoor household purposes. Due to the chemical nature of PBDEs, they have not been detected in water to any significant extent; therefore, drinking water is not expected to be a major route of exposure to PBDEs. The World Health Organization (WHO) has not established any drinking water guidelines for PBDEs, US EPA has not set drinking water standards for PBDEs, and the United States Food and Drug Administration (US FDA) has not set allowable levels for PBDEs in bottled water. However, existing standards should be reviewed to ensure that they are based on the latest science, to assist states/provinces in identifying areas where concentrations of PBDE in drinking water might be elevated, and to ensure that all available knowledge and tools are used to minimize exposure.

Summary of Domestic Water Quality Options

- Obtain and analyze monitoring data on PBDE concentrations in drinking water and develop domestic water quality standards, if necessary (US)

6 Conclusions

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

Binational efforts are needed to reduce the risks that PBDEs pose to human health and the environment. Binational cooperation is needed to coordinate monitoring and surveillance efforts, maximize research initiatives to identify PBDE sources, and cost-effectively monitor and track PBDE 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 implement 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 PBDEs 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 PBDEs*

Property	PBDE Mixtures		
	Pentabromodiphenyl ether (PentaBDE)	Octabromodiphenyl ether (OctaBDE)	Decabromodiphenyl ether (DecaBDE)
Molecular Weight	Mixture	Mixture	959.22
Color	Clear, amber to pale yellow	Off-white	Off-white
Physical State	Highly viscous liquid	Powder	Powder
Melting Point	-7 to -3°C (commercial)	85-89°C (commercial); 200°C (range, 167-257); 79-87°C; 170-220°C	290-306°C
Boiling Point	>300°C (decomposition starts above 200°C)	Decomposes at >330°C (commercial)	Decomposes at >320, >400, and 425°C
Density, g/mL	2.28 at 25°C; 2.25-2.28	2.76; 2.8 (commercial)	3.0; 3.25
Odor	No data	Faint	Odorless
Solubility			
Water	13.3 µg/L (commercial); 2.4 µg/L (pentabromodiphenyl ether component); 10.9 µg/L (tetrabromodiphenyl ether component)	<1 ppb at 25°C (commercial); 1.98 µg/L (heptabromodiphenyl ether component)	<0.1 µg/L
Organic solvent(s)	10 g/kg methanol; miscible in toluene	Acetone (20 g/L); benzene (200 g/L); methanol (2 g/L) all at 25°C	No data
Partition Coefficients			
Log K_{OW}	6.64-6.97; 6.57 (commercial)	6.29 (commercial)	6.265
Log K_{OC}	4.89-5.10	5.92-6.22	6.80
Vapor Pressure	2.2×10^{-7}-5.5×10^{-7} mm Hg at 25°C; 3.5×10^{-7} mm Hg (commercial)	9.0×10^{-10}-1.7×10^{-9} mm Hg at 25°C; 4.9×10^{-8} mm Hg at 21°C (commercial)	3.2×10^{-8} mm Hg
Henry's Law Constant (atm-m^3/mole)	1.2×10^{-5}; 1.2×10^{-6}; 3.5×10^{-6}	7.5×10^{-8}; 2.6×10^{-7}	1.62×10^{-6}; 1.93×10^{-8}; 1.2×10^{-8}; 4.4×10^{-8}
Autoignition temperature	Decomposes above 200°C	Decomposes above 330°C (commercial)	Not applicable
Flashpoint	No data	No data	None
Flammability Limits	Not applicable (flame retardant)	Not applicable (flame retardant)	Non-flammable
Conversion Factors	1 ppm=23.48mg/m^3 at 20°C	No data	No data
Explosive Limits	None	None	No data

Source: ATSDR (2017)

Table 2. *Estimated Quantities of PBDEs in the Great Lakes Basin*

PBDE	Tonnage Range, metric tons (year)	Where Found, % of total PBDE use	% Expected to Enter Waste Phase or Remain in Use by 2020
PentaBDE	2000-10,000 (2004)	Furniture foams 60-65% Vehicle foams 30-35% EEE 2-3%	All to leave the use phase
OctaBDE	500-2,000 (2004)	EEE 90% Auto sector 10%	90% to leave the use phase
DecaBDE	10,000-70,000 (2013)	Automotive 25% Textiles 25% Construction materials 25% EEE 15%	50% remain in use (of 2008 peak inventory)
Total PBDEs	15,000-80,000 (2004)		40% of the peak value (mainly decaBDE) remain in use

EEE – electronics and electrical equipment
Source: Abbasi et al. (2014)

Table 3. *Brominated Flame Retardants Measured in IADN.*

BDE-7	BDE-139	BDE-206
BDE-10	BDE-140	BDE-207
BDE-15	BDE-153	BDE-208
BDE-17	BDE-154	BDE-209
BDE-28	BDE-156	DBDPE
BDE-30	BDE-169	HBCDD
BDE-47	BDE-180	BTBPE
BDE-49	BDE-183	*Syn*-DP
BDE-66	BDE-184	*Anti*-DP
BDE-71	BDE-191	PBBZ
BDE-85	BDE-196	pTBX
BDE-99	BDE-197	EHTBB
BDE-100	BDE-201	BEHTBP
BDE-119	BDE-203	PBEB
BDE-126	BDE-204	HBB
BDE-138	BDE-205	BB-153

HBCDD: Hexabromocyclododecane; DBDPE: Decabromodiphenyl ethane; BTBPE: 1,2-Bis(2,4,6-tribromophenoxy)ethane; DP: Dechlorane Plus; PBBZ: pentabromobenzene; pTBX: tetrabromo-p-xylene; EHTBB: 2-ethylhexyl tetrabromobenzoate; EHTBP: bis(2-ethylhexyl)tetrabromophthalate; PBEB: pentabromoethyl benzene; HBB: hexabromobenzene; BB: brominated biphenyl

Table 4. *United States Standards and Recommendations for PBDEs*

Agency	Focus	Level	Source
American Industrial Hygiene Association	Workplace Air	5 mg/m^3 for decaBDE; ongoing air monitoring if dust levels of pentaBDE and octaBDE exceed 5 mg/m^3	US EPA (2014b)
Agency for Toxic Substances and Disease Registry (ATSDR)	Oral and Inhalation Exposure Minimal Risk Level	**DecaBDE:** 0.0002 mg/kg/day (intermediate-duration oral exp.); 0.01 mg/kg/day (acute – duration oral exp.) **OctaBDE:** 0.006 mg/m^3 (intermediate – duration inhalation exp.) **PentaBDE:** 0.00006 mg/kg/day (acute-duration oral exp.)	ATSDR (2017)
US Environmental Protection Agency	Oral Reference Dose*	**PentaBDE:** $2x10^{-3}$ mg/kg/day **OctaBDE:** $3x10^{-3}$ mg/kg/day **DecaBDE:** $7x10^{-3}$ mg/kg/day	US EPA (2018)

*An estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime (US EPA, 2018).

Table 5. Canadian Federal Environmental Quality Guidelines for PBDEs

Homologue*	Congener	Water (ng/L)	Fish Tissue (ng/g ww)	Sediment ** (ng/g dw)	Wildlife Diet[†] (ng/g ww food source)	Bird Eggs (ng/g ww)
triBDE	total	46	120	44	–	–
tetraBDE	total	24	88	39	44	–
pentaBDE	total	0.2	1	0.4	3 (mammal) 13 (birds)	29[‡]
pentaBDE	BDE-99	4	1	0.4	3	–
pentaBDE	BDE-100	0.2	1	0.4	–	–
hexaBDE	total	120	420	440	4	–
heptaBDE	total	17[||]	–	–	64	–
octaBDE	total	17[||§]	–	5600[§]	63[§]	–
nonaBDE	total	–	–	–	78	–
decaBDE	total	–	–	19[§#]	9	–

Source: Environment Canada (2013).

***Canadian** FEQG for triBDE (tribromodiphenyl ether), tetraBDE (tetrabromodiphenyl ether), hexaBDE (hexabromodiphenyl ether), heptaBDE (heptabromodiphenyl ether), nonaBDE (nonabromodiphenyl ether) and decaBDE (decabromodiphenyl ether) are based on data for the congeners: BDE-28, BDE-47, BDE-153, BDE-183, BDE-206, and BDE-209, respectively unless otherwise noted.

**Values normalized to 1% organic carbon.

[†]Applies to mammalian wildlife unless otherwise noted.

[‡] Value based on the commercial PentaBDE formulation, DE-71, which contains mostly pentaBDE and some tetraBDE.

[||]Values based on commercial OctaBDE mixture DE-79, which is composed mainly of heptaBDE and octaBDE (octabromodiphenyl ether).

[§]Values adopted from Ecological Screening Assessment Report (Environment Canada 2006). Sediment guidelines for octaBDE and decaBDE were adapted from the SAR by being corrected for the sediment organic carbon in the actual tests, then normalised to 1% organic carbon instead of the 4% in the SAR.

[#]Values based on commercial decaBDE mixture which is composed mainly of nonaBDE and decaBDE.

8 Figures

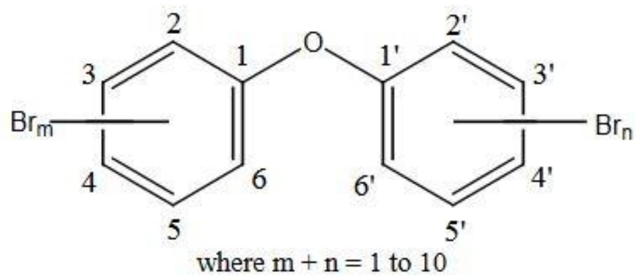

Figure 1. *General Chemical Structure of PBDEs. Source: ATSDR (2017)*

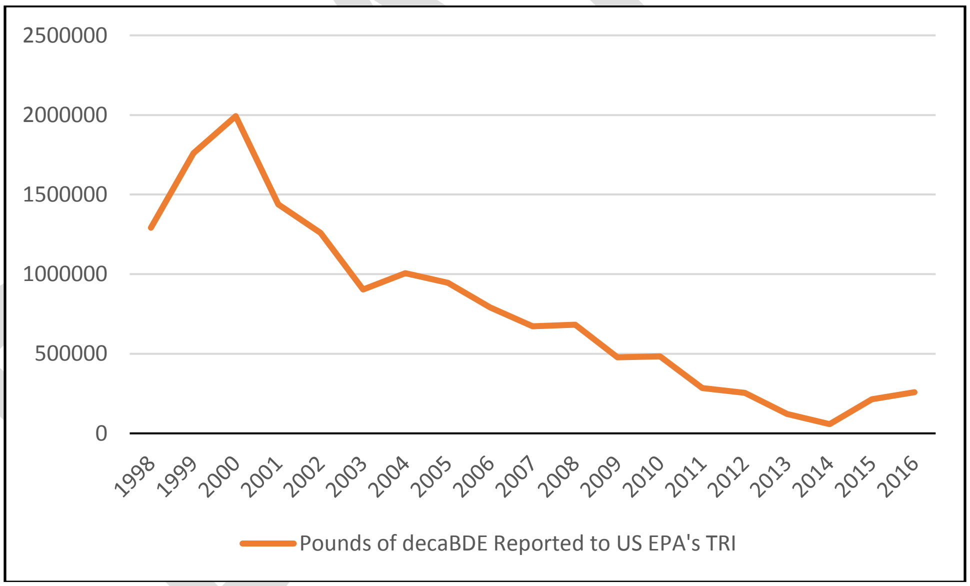

Figure 2. *Total Releases (All Sources) of DecaBDE, 1998-2016. Source: US EPA (2017b)*

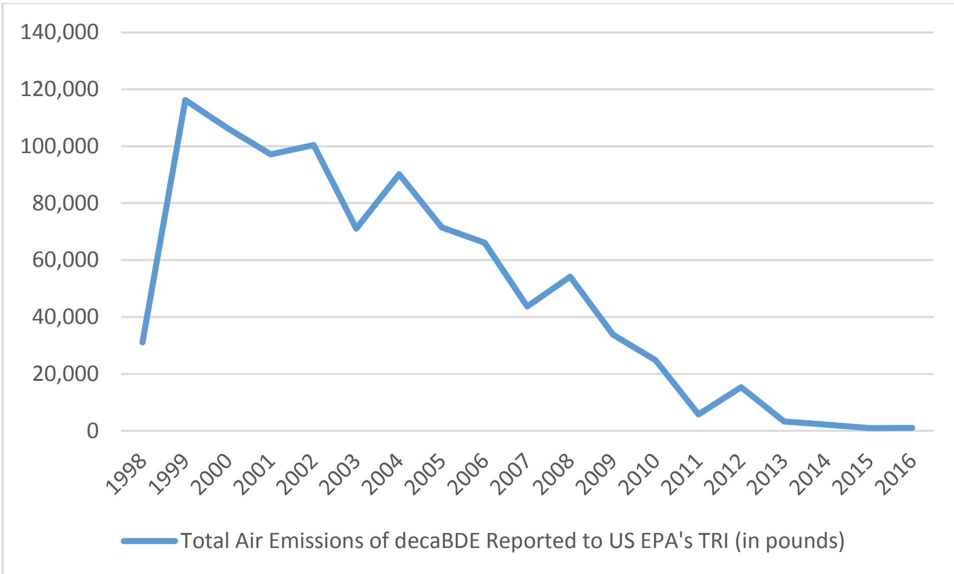

Figure 3. *Total Air Emissions of DecaBDE, 1998-2016. Source: US EPA (2017b)*

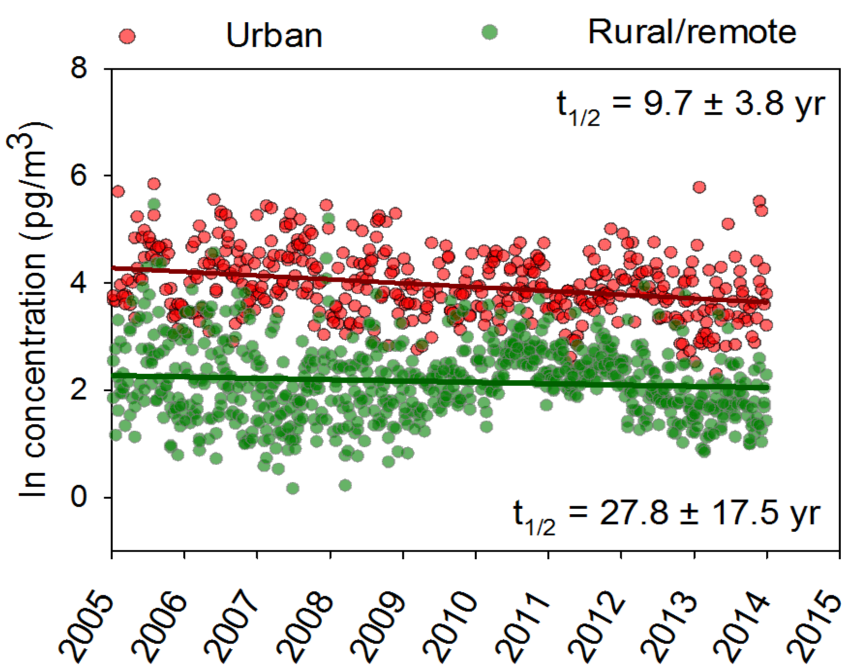

Figure 4. *PBDE trends at urban and rural/remote US IADN sites. Source: IADN, Indiana University, 2017*

Note that the levels at the urban sites are decreasing with halving times of about 10 years, but those levels at the rural and remote sites are changing slowly (this regression is significant but slow). This means that the voluntary phase out of PBDEs between 2004 and 2013 seems to be working – faster in Chicago and Cleveland but slower elsewhere.

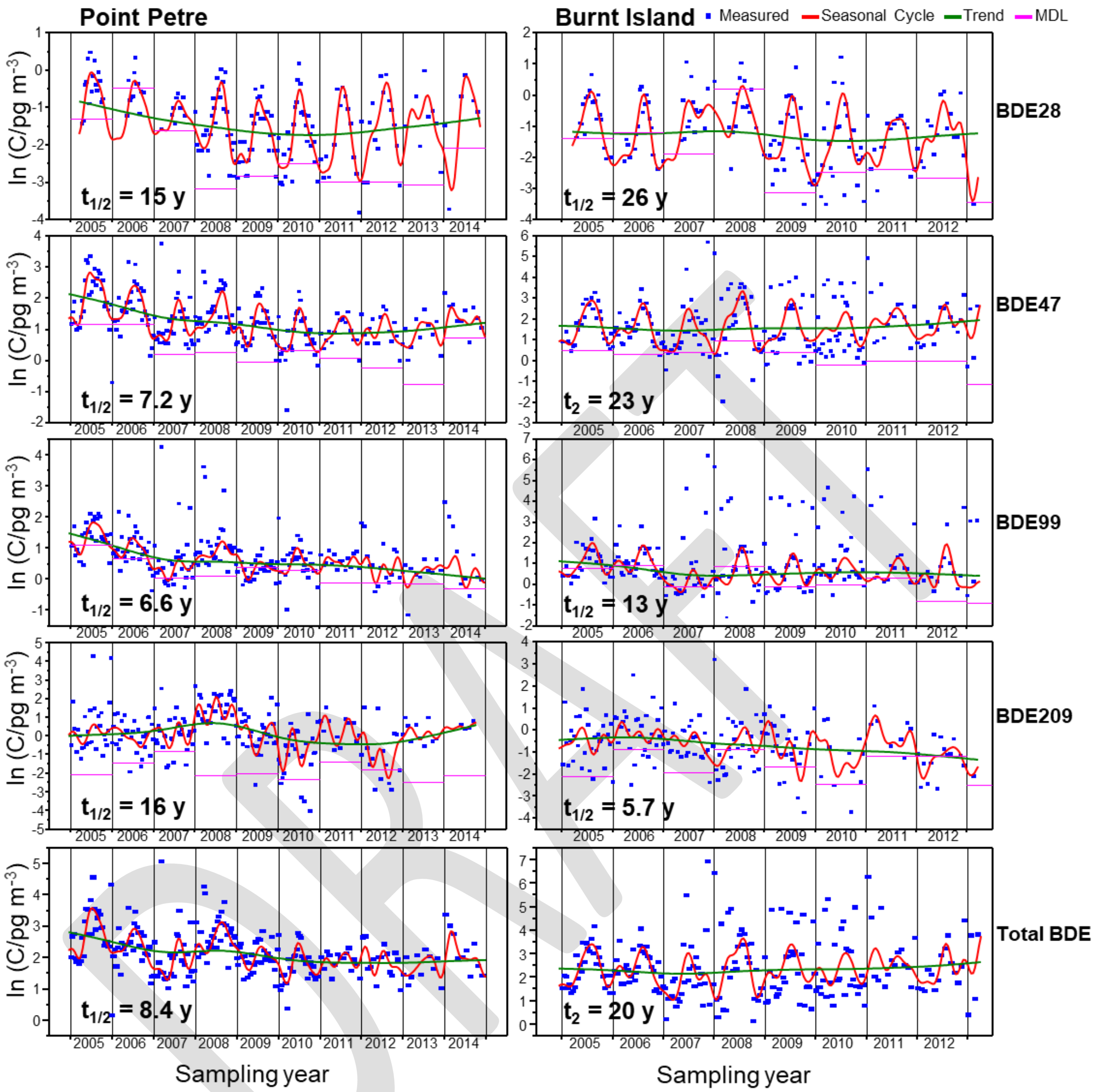

Figure 5. *Seasonal cycles, trends and measurements of BDE-28, -47, -99, -209 and total PBDEs at Burnt Island and Point Petre. Source: Shunthirasingham et al. (2018)*

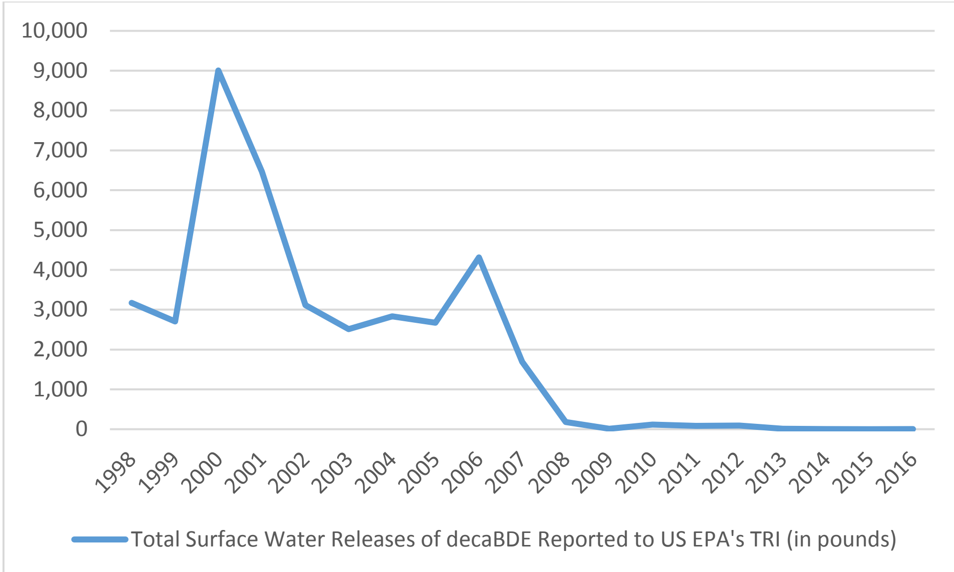

Figure 6. *Total Surface Water Releases of DecaBDE, 1998-2016. Source: US EPA (2017b)*

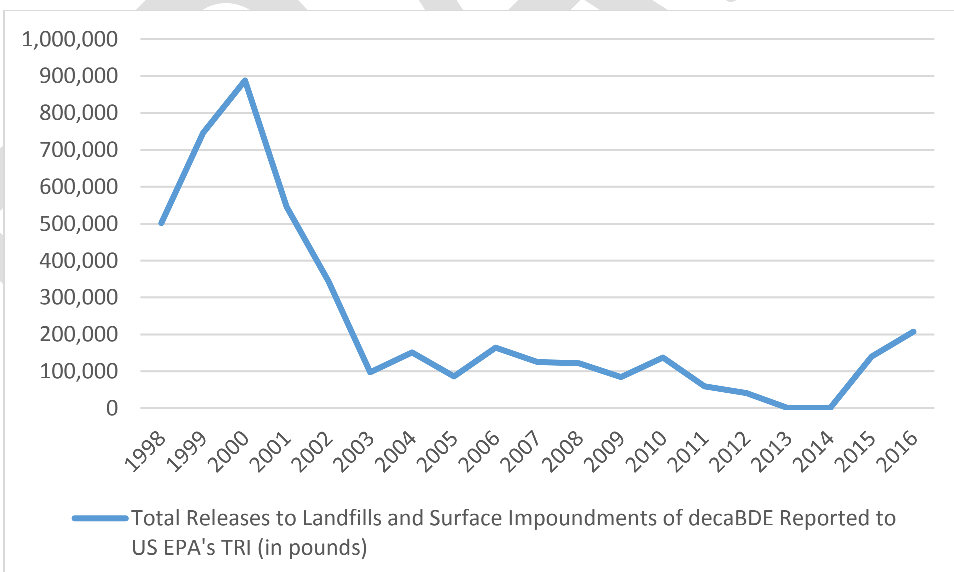

Figure 7. *Total Releases to Landfills and Surface Impoundments of DecaBDE, 1998-2016. Source: US EPA (2017b)*

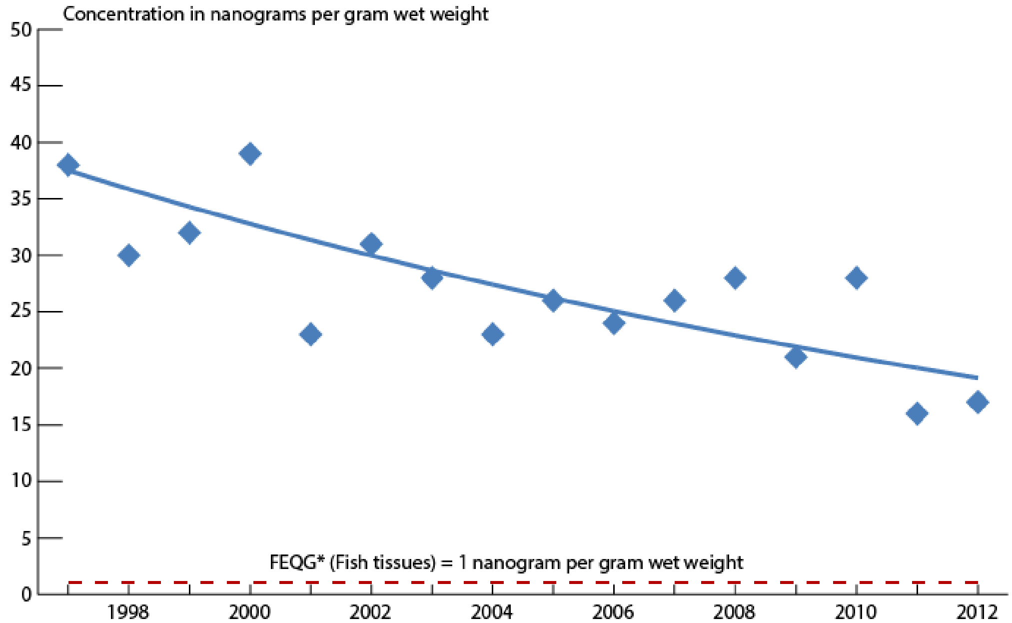

Figure 8. *PentaBDE concentrations in lake trout, 1997-2012. Source: ECCC (2017)*

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