Great Lakes Binational Strategy for Mercury Risk Management

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

Disclaimer

The purpose of this document is to propose mercury 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 mercury, into the air, water, land, sediment, and biota of the Great Lakes basin ecosystem. Under the GLWQA, Canada and the United States ("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 (the Strategy) for mercury to focus efforts of the Governments of Canada and the United States, and their many partners[1] in implementing risk mitigation and management options aimed at reducing mercury in the Great Lakes basin. The Parties will use this Strategy as guidance to identify, prioritize, and implement actions to reduce the anthropogenic releases of mercury into the Waters of the Great Lakes. 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 Strategy includes a listing of options that can be undertaken by the Parties, with the support of their many partners, to achieve continuing and increased reductions of mercury in the Great Lakes basin. In addition, some of the listed options reflect work that the Parties are already performing.

Mercury is a naturally occurring metallic element that has been used in a variety of applications and is released from both natural and anthropogenic sources. Once in the environment, mercury can convert to its highly bioaccumulative organic form, methylmercury, which is highly toxic and bioavailable when ingested. Concentrations of mercury exceed human and ecological risk thresholds in many areas of the Great Lakes and elevated mercury concentrations are the cause for some fish consumption advisories in all of the Great Lakes. Due to its adverse effects in humans and wildlife, mercury has been widely studied, monitored, regulated, and targeted for action in Canada, the United States, and globally. Yet mercury continues to be a threat to ecosystems and human health and more work needs to be done to reduce mercury levels in the Great Lakes basin.

In addition to identifying options, the Strategy identifies multiple knowledge gaps that require further investigation:

- An overall lack of knowledge as to how a changing climate may impact the mercury cycle;
- A need to enhance emissions data and apply innovative tools, such as isotopic mercury ratios, to improve the ability of current models to predict the relationship between mercury emissions and fish concentrations; and
- A need for comprehensive evaluation of how well existing regulatory programs are working to limit and reduce mercury impacts on the Great Lakes.

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[1] 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

To address these gaps, this Binational Strategy document proposes multiple strategic options as outlined in **Table A** of the Executive Summary**.** Many of the options presented in this Binational Strategy are already underway, such as implementation of obligations under the Minamata Convention. These and new activities, such as enhancing models and data collection tools, will contribute to the reduction of mercury levels in the Great Lakes ecosystem. Where Canada or the United States are not listed with a specific activity, it reflects the fact that the option presented has already been undertaken or is not appropriate within the context of the existing risk management programs and activities, within that country.

***Table A**. Summary of the Canada-United States Strategic Options for Mercury*

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				
Evaluate the effectiveness of existing regulatory programs to ensure maximum efficiency and overall positive implications on a global scale (Canada) Review and update actions to match current scientific understanding and regional context (Canada) Identify any manufacturing processes or products that intentionally add mercury (US) Continue to reduce mercury emissions resulting from coal-fired generation of electricity (Canada) Continue implementation of domestic regulations and other risk management activities for mercury (Canada and US) Implement the National Strategy for Safe and Environmentally Sound Disposal of Lamps Containing Mercury (Canada) Continue remediation of mercury-contaminated sites and sediments (Canada and US) Amend the *Products Containing Mercury Regulations* to further reduce mercury in products (Canada)	Continue to ensure compliance with domestic and international mercury activities and initiatives (Canada and US) Continue implementation of respective obligations of the Minamata Convention on Mercury (Canada and US)	Enhance public outreach and educate the public and facility staff on potential sources of mercury and proper actions to follow when handling mercury containing products (Canada and US) Enhance public outreach and education on site-specific fish consumption advisories (Canada and US) Encourage industries to track their P2 activities and efforts in the National Pollutant Release Inventory (NPRI) or Toxics Release Inventory (TRI), or via P2 promotion activities (fact sheets, case studies) (Canada and US) Highlight pollution prevention successes (Canada and US) Implement best available techniques and best environmental practices for new and substantially modified sources (Canada)	Continue monitoring mercury in environmental media in the Great Lakes (air, precipitation, sediment, fish, and other wildlife) and publish results in a variety of publications (e.g., online and open data portals, government reports and scientific journals) to maximize the intended audience (Canada and US) Continue efforts to update and maintain domestic mercury emissions inventories in a manner such that regional and global emissions can be tabulated (Canada and US) Conduct additional research on methylation dynamics and the differential impacts of mercury in nearshore versus offshore environments (Canada and US) Utilize and, as feasible, enhance existing models to track long-range atmospheric transport and the rate of methylmercury formation in the environment and its corresponding ecological risk (Canada and US) Develop cost-effective, reliable and effective tools (e.g., passive samplers) for collecting long-term mercury multi-media monitoring data (Canada and US) Develop and populate a structured data system to track mercury sources, manifests, waste, and products (Canada)	Review and update existing domestic water quality standards, if necessary (Canada and US)

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Acronyms and Abbreviations

ACAP	Arctic Contaminants Action Plan
AMAP	Arctic Monitoring and Assessment Program
AMNet	Atmospheric Mercury Network
AOC	Areas of Concern
ASGM	Artisanal and small-scale gold mining
CAA	Clean Air Act
CAMNet	Canadian Atmospheric Mercury Measurement Network
CAPMoN	Canadian Air and Precipitation Monitoring Network
CARA	Clean Air Regulatory Agenda
CWA	Clean Water Act
CCME	Canadian Council of Ministers of the Environment
CEC	Commission for Environmental Cooperation
CEPA	Canadian Environmental Protection Act
CEQG	Canadian Environmental Quality Guidelines
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CHMS	Canadian Health Measures Survey
CMC	Chemicals of Mutual Concern
CNR	Consiglio Nazionale delle Ricerche (Institute for Atmospheric Pollution, Italy)
COP1	Minamata Convention on Mercury
CSMI	Cooperative Science and Monitoring Initiative
CWS	Canada-Wide Standards
ECCC	Environment and Climate Change Canada
ECCC-AMM	Environment and Climate Change Canada – Atmospheric Mercury Monitoring
EPCRA	Emergency Planning and Community Right-to-Know Act
FCMSP	Fish Contaminants Monitoring and Surveillance Program
FNBI	First Nations Biomonitoring Initiative
GLBTS	Great Lakes Binational Toxics Strategy
GLENDA	Great Lakes Environmental Database
GLNPO	Great Lakes National Program Office
GLRC	Great Lakes Regional Collaboration
GLPI	Great Lakes Protection Initiative
GLRI	Great Lakes Restoration Initiative
GLWQA	Great Lakes Water Quality Agreement
Hg	Mercury
HgS	Mercuric Sulfide, Cinnabar
IADN	Integrated Atmospheric Deposition Network
ITT	Identification Task Team
LAMP	Lakewide Action and Management Plan
LRTAP	Long-Range Transboundary Air Pollution
LSBP	Lake Superior Binational Program
MACT	Maximum Achievable Control Technology
MATS	Mercury and Air Toxics Standards
MDN	Mercury Deposition Network
MEBA	Mercury Export Ban Act of 2008
MECP	Ministry of Environment, Conservation and Parks
MPO	Manufactured, Processed, or Otherwise Used

NADP	National Atmospheric Deposition Program
NARAP	North American Regional Action Plan
NAtChem	National Atmospheric Chemistry (Database)
NCP	Northern Contaminants Program
Ni-Cd	Nickel Cadmium
NPRI	National Pollutant Release Inventory
NRDC	Natural Resources Defense Council
P2	Pollution Prevention
PCB	Polychlorinated Biphenyl
POTW	Publicly Owned Treatment Works
PRTR	Pollutant Release and Transfer Registry
RCRA	Resource Conservation and Recovery Act
SDWA	Safe Drinking Water Act
SiGL	Science in the Great Lakes
SOLEC	State of the Lakes Ecosystem Conferences
SSLA	Small Sealed Lead-Acid
TGM	Total Gaseous Mercury
TPM	Total Particulate Mercury
TRI	Toxics Release Inventory
TSCA	Toxic Substances Control Act
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
US EPA	United States Environmental Protection Agency
US FDA	Food and Drug Administration (US)
USGS	United States Geological Survey
ZDDP	Zero Discharge Demonstration Program

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, tribal/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 Parties designated mercury as one of eight CMCs. In designating mercury 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. To summarize, the purpose of the binational strategies is therefore to reduce releases of CMCs by focusing the efforts of governments, agencies, and (where appropriate) the public on 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 US EPA's Great Lakes National Program Office (GLNPO) coordinates these efforts. Within Canada, Environment and Climate Change Canada'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 sufficient actions such 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.

This mercury strategy covers a list of 22 potential management options, in Canada and/or the United States, that are being or could be readily implemented to address threats to water quality by reducing mercury 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. As noted in the GLWQA, the Parties' respective obligations are subject to the appropriation of funds in accordance with their respective procedures. The Strategy is a compilation of options that can be considered by a variety of stakeholders, including industry, academia, and non-government organizations. In addition, some of the options reflect work that the Parties are already performing. 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 part of the process of designating mercury as a CMC is available in the Binational Summary Report: Mercury produced by the GLWQA Annex 3 Subcommittee Identification Task Team (ITT) (2015). The Extent and Effects of Mercury Pollution in the Great Lakes Region, Great Lakes Mercury Connections, a synthesis published by the Biodiversity Research Institute with the Great Lakes Commission and the University of Wisconsin-La Crosse, provides an overview of sources, cycling, and impacts of mercury (Evers et al., 2011). The Canadian Mercury Science Assessment Report (ECCC 2016) also provides a comprehensive scientific evaluation and synthesis of mercury in the Canadian environment.

2.1 Chemical Identity

Mercury (Hg) is a naturally occurring metallic element. There are three forms of mercury: elemental, inorganic, and organic mercury compounds. Elemental mercury is a heavy, silvery-white liquid metal, and is the only metallic element that is liquid at room temperature. Inorganic mercury compounds occur when mercury combines with elements other than carbon, such as chlorine, oxygen, or sulfur. Inorganic mercury compounds, also called mercury salts, are mostly white powders or crystals, except for mercuric sulfide (cinnabar), which is red and turns black after exposure to light. Mercury combined with carbon forms organic mercury compounds; methylmercury is the most common organic mercury in the environment (US EPA, 2017b).

2.2 Physical and Chemical Properties

Mercury is valued for use in industrial applications due to its physio-chemical properties of high surface tension, high specific gravity, low electrical resistance, high reflectance, and constant volume of expansion in the liquid state (Schroeder and Munthe, 1998; Park and Zheng, 2012). Compared with other metals, mercury is a poor conductor of heat and a fair conductor of electricity. Select physical and chemical properties of mercury and common mercury compounds are shown in **Table 1**. When naturally occurring, mercury is a metal that is principally in the form of the inorganic mineral cinnabar (HgS) (Michigan DEQ and US EPA, 2018). The cinnabar form is an insoluble and stable compound (ATSDR, 2013). However, natural or anthropogenic releases of inorganic mercury to the environment allow for natural biological processes to convert inorganic mercury to the more toxic organic form of methylmercury (Schroeder and Munthe, 1998).

2.3 Environmental Fate and Transport

The simplified mercury cycle illustrated in **Figure 1** shows how mercury enters and cycles through ecosystems, biomagnifies in the food chain, and bioaccumulates in fish and wildlife (Evers et al., 2011). Within the aquatic environment, inorganic mercury can be converted into methylmercury through a series of complex processes often involving sulfate-reducing bacteria typically in wetlands and sediments (Evers et al., 2011).

In most ecosystems, large pools of mercury are present in soils and sediments, however much of this mercury may not be readily available for methylation. Mobilization of mercury from soils, as well as the production of methylmercury, can be enhanced by land-use changes, such as agriculture, forestry, and reservoirs. Changes in mercury loading (increase or decrease) will yield a response in levels of methylmercury in fish, but the timing and magnitude of the response will vary depending of ecosystem-specific variables and the form of the mercury loaded. Sulfate and microorganism populations, along with pH and dissolved organic carbon, have been identified as parameters that relate mercury levels in fish among water bodies (Munthe, et al., 2007).

Methylmercury bioaccumulates and biomagnifies through the food chain, with levels increasing from small aquatic organisms, to small fish to larger fish, to wildlife. This may create a significant source of dietary exposure to humans who consume fish or wildlife. Top predatory fish such as walleye and lake trout can have mercury concentrations more than one million times higher than that of the surrounding water (International Joint Commission, 2015).

Atmospheric emissions of mercury can result from natural processes, including forest fires and volcanic activity, and anthropogenic processes such as the combustion of coal or industrial activities (Cohen et al., 2007; Evers et al., 2011). Mercury emitted from anthropogenic sources may remain in the atmosphere for six months to a year, enabling long-range transport (International Joint Commission, 2015) prior to eventual atmospheric deposition (Evers et al., 2011). Deposition can take the form of wet or dry deposition. In wet deposition, mercury is removed from the atmosphere and deposited back on the Earth in the form of precipitation (e.g., rain, snow) (Evers et al., 2011). In dry deposition, mercury is removed from the atmosphere and deposited as a gas or particle (Evers et al., 2011). As a result of wet or dry deposition, mercury can accumulate on trees, soil, water, or other surfaces (Cohen et al., 2007). In addition to long-range transport and deposition, mercury can also deposit locally, depending primarily on its oxidation state. Gaseous oxidized and particulate mercury forms generally deposit much more rapidly than elemental mercury and have a much shorter atmospheric residence time (on the order of days to weeks). Although the oxidized forms make up a small fraction of total atmospheric mercury, they can be a large part of total mercury deposition (wet+dry).

2.4 Sources and Releases of Mercury in the Great Lakes

Natural emissions of mercury result from its presence in the Earth's crust and are produced by volcanic and geothermal activity, soils enriched with mercury-containing minerals, forest fires, and erosion of mineral deposits.

Atmospheric emission and deposition is now identified as the greatest source of mercury to the Great Lakes basin (Evers et al., 2011). Atmospheric mercury can travel from distant global and regional sources, or can be released locally and remain in the Great Lakes basin (Evers et al., 2011). An isotopic mixing model (Lepak et al. 2015) identified three primary mercury sources for sediments: atmospheric, direct industrial, and watershed-derived. Results indicate atmospheric sources dominate in Lakes Huron, Superior, and Michigan sediments, while watershed-derived and industrial sources dominate in Lakes Erie and Ontario sediments. Comparison of signatures in predatory fish from three lakes reveals that bioaccumulated mercury is more isotopically similar to atmospherically derived mercury than a lake's sediment. An improved global emission inventory for the period 1990 to 2010 (Zhang et al. 2016) found a 20% decrease in total mercury emissions and a 30% decrease in anthropogenic elemental mercury emissions, with much larger decreases in North America and Europe offsetting the effect of increasing emissions in Asia. The large trends observed in North America and Europe reflect the phase-out of mercury from commercial products as well as the co-benefit from sulfur dioxide (SO_2) and nitrogen oxides (NOx) emission controls on coal-fired utilities.

2.4.1 Uses and Quantities in Commerce

Historically, mercury-added products have been widely used in residential, commercial, industrial, military, marine, and medical environments. However, since 1980, the use of mercury in products sold in the United States has decreased more than 97 percent. Major remaining mercury-added product categories for the United States are listed in **Table 2** (US EPA 2017c, IMERC). These include industrial products and components, such as switches and relays, dental amalgam, thermostats, lamps, button cell batteries, and formulated products such as coating materials, acids, alkalis, bleach, pharmaceutical products, stains, reagents, preservatives, cosmetics, and dyes (Carpenter et al., 2011). Current global uses for commodity mercury include vinyl chloride monomer (VCM) production, small-scale artisanal gold mining (ASGM) operations, mercury cell chlor-alkali processes, and various consumer goods including compact fluorescent light bulbs and other lamps (Carpenter et al., 2011). The U.S. does not use mercury VCM or ASGM processes and Canada does not engage in either process.

In Canada, the *Products Containing Mercury Regulations* prohibit the import and manufacture, since November 8, 2015, of products containing mercury, with some exemptions for essential products that have no technically or economically viable alternatives. Data received during the 2017 reporting period indicates that products containing mercury imported or manufactured in Canada during 2016 represented approximately one metric tonne of mercury and were mainly dental amalgam and lamps. Mercury and its compounds are listed as prohibited ingredients on the Cosmetic Ingredient Hotlist. As such, their use is not permitted in cosmetic products in Canada.

According to the reporting requirements of the Ontario Toxics Reduction Act, 2009, manufacturing and mineral processing facilities in Ontario used 10,031 kg of mercury and mercury-containing compounds, with 8,137 kg contained in products. In reviewing specific data from 2012 in the Great Lakes basin watershed, facilities reported the use of approximately 8,500 kg and 7,200 kg of mercury and mercury-containing compounds respectively in products (OMOECC, 2014).

The only known current use of elemental mercury in a U.S. manufacturing process is in the production of chlorine and caustic soda using mercury cell technology. Most U.S. facilities that used the mercury cell process have closed or converted to mercury-free manufacturing technologies; the number of operating mercury cell plants in the United States has declined from 14 facilities in 1996 to 2 facilities in 2013. An estimated 368 metric tons of elemental mercury were in use by the chlor-alkali industry in 2013 (U.S. EPA 2017c). There are no mercury cell chlor-alkali plants in Canada; the last mercury cell chlor-alkali plant closed in 2008 (ECCC, 2016a).

In 2017, UNEP estimated the average global supply of mercury in 2015 at approximately 3480-4785 metric tons per year (UNEP 2017). Mining of metallic mercury contributes to the global supply of mercury. Mercury is currently mined only in China, Mexico, Indonesia and the Kyrgyz Republic (European Commission, 2017). The main sources of mercury for the global market, based on 2007 data, are summarized in **Table 3**.

The industrial use of mercury is increasingly recognized as posing a liability, therefore the United States and other countries have begun to accumulate a large surplus of commodity mercury (i.e., manufactured or recovered and sold or stored for later use)[2] (Carpenter et al., 2011). According to US EPA (2017), there are currently two primary sources of commodity mercury supply in the United States:

- Byproduct from metal mining and processing

[2] Commodity mercury is defined as 99.99% pure by volume Carpenter, C., L. O'Conor, J. Elmer and D. DePinho (2011). Assessing the Impacts of the Mercury Export Ban Act of 2008 on the U.S. Mercury Recycling Industry. WM11 Global Achievements and Challenges in Waste Management, Phoenix, AZ.

- Recovery from treatment of waste

US EPA estimates by-product elemental mercury production at 12 metric tons in 2011 and the quantity of mercury recovered from treatment of hazardous waste to be 66 metric tons in 2013 (US EPA 2017c).

According to the Associations of Lighting and Mercury Recyclers (ALMR), more than 60 companies recycle mercury-containing products in the United States. There are facilities in the Great Lakes basin in Wisconsin, Minnesota, Illinois and Pennsylvania, however not all of these facilities retort mercury, but only recover mercury for further processing. Four main recycling companies specialize in retorting or reprocessing mercury waste to commodity-grade mercury. One of these is located in Illinois, two are located in Pennsylvania and one in Minnesota (US EPA 2007).

According to the Iron Mining Association of Minnesota there are currently eight companies mining or planning to mine iron ore in Minnesota (http://taconite.org/mining-industry/mines). To date, a precious metals mine has been permitted in the upper peninsula of Michigan and a second copper and zinc mine is seeking permit approval in Northeastern Minnesota. Mercury from the iron mining industry (stack emissions from taconite processing) in northeastern Minnesota is the principal mining related source in the Great Lakes basin. According to Berndt (2003), mercury emissions in 2000 of 342 kg/year from one facility were predominantly elemental and hence not deposited locally. Other research has noted that isolated point-source mercury emitters including coal-fired boilers, waste incinerators, and taconite-processing plants could contribute to higher mercury deposition in parts of northeastern Minnesota (Engstrom et al., 2007).

2.4.2 Sources of Emissions and Releases

Both natural and anthropogenic activities contribute to the mercury cycle. Natural sources of mercury, such as volcanic eruptions and emissions from the ocean, have been estimated to contribute about one-third of current worldwide mercury air emissions, whereas anthropogenic emissions account for the remaining two-thirds (GLRC, 2010). Anthropogenic emissions, once deposited, can be re-emitted. Like natural emissions, these re-emissions are believed to be largely in the form of elemental mercury (Cohen et al., 2007). Much of the mercury circulating through the environment today is likely mercury that was released years ago when mercury was frequently used in many industrial, commercial, and residential products and processes (GLRC, 2010), although the ocean has become a significant sink (Lamborg et al. 2014).

Initial regulatory attention to sources of mercury in the 1970s focused on large industrial chlor-alkali plants and pulp and paper mills that discharged mercury directly to the Great Lakes and to the rivers and streams draining into the lakes. Mercury has also been emitted into the atmosphere by municipal and medical waste incinerators (NYSDEC, 2017). Atmospheric emissions and deposition were identified as the largest source of mercury to the Great Lakes basin in a 2010 report (GLRC, 2010), with the greatest proportion of mercury released into the atmosphere originating from coal-fired electric power plants. Coal-fired electric generating plants were phased out in Ontario in 2014. However, coal-fired electric generating plants are currently in use in states in the Great Lakes basin.

As shown in **Figure 2**, there was a 50% decline in anthropogenic mercury emissions in the Great Lakes states between 1990 and 2005 (Evers et al., 2011). This decline is likely the result of provincial, state, regional, binational, and voluntary actions to control mercury emissions. Canadian inventories reported an 85% decrease in mercury air emissions between 1990 and 2010 (**Table 4**) (ECCC, 2016a). As of 2011, coal-fired power plants were identified as the largest source of anthropogenic mercury atmospheric emissions in the Great Lake states, contributing approximately 39% of total anthropogenic mercury emissions (NEI, 2011). Coal-fired plants were identified as the highest individual contributors at the state or provincial level in the Great Lake basin, with the exception of Minnesota and New York (Evers et al., 2011). Coal-fired electricity generating plants in Canada are in the process of being phased out (Sibbald, 2016) and were closed in Ontario by 2014. The Mercury and Air Toxic Standards (MATS) and other factors (e.g., fuel switching to natural gas) have contributed to a significant decline in mercury emissions from coal-fired power plants in the U.S. Overall, mercury emissions sources have decreased in Canada, the United States, and Europe (Evers et al., 2011). However, global emissions of mercury are on the rise, mainly due to contributions from Asia (Evers et al., 2011). It has been estimated that mercury emissions from Asia now account for ~50% of the total anthropogenic emissions (ECCC, 2016a).

In 2005, metal ore processing was the second largest contributor and accounted for 14% of atmospheric mercury emissions in the Great Lakes states (ITT, 2015). Other stationary sources are medical and municipal waste incinerators and industrial boilers (Evers et al., 2011). Other major anthropogenic sources of mercury include the use and disposal of mercury-containing products, processing of metals, and the manufacturing of cement (Michigan DEQ and US EPA, 2018).

By using stable mercury isotopes, researchers are now able to assess sources of mercury in Great Lakes sediments. Mercury isotopes in Great Lakes precipitation can also be used as a tool for source attribution (Sherman and Blum, et al., 2016). Atmospheric (precipitation)-derived mercury sources dominate the sediments of Lakes Superior, Huron, and Michigan, whereas watershed and industrial mercury sources dominate the sediments of Lakes Erie and Ontario (Evers et al., 2011). Mercury can also be introduced to water bodies from water treatment facilities or landfill leachate that becomes contaminated from the use and disposal of consumer products containing mercury, such as batteries, light bulbs (i.e., fluorescent lights and compact fluorescent bulbs), and electrical switches (US EPA, 2017b). Much of the point-source mercury pollution from chlor-alkali facilities has been controlled, allowing partial recovery of the Great Lakes, as shown by lower mercury concentrations in lake sediments in the lower Great Lakes (e.g., Lake Ontario), declines in fish mercury concentrations since the 1970s, and the advent of regulatory attention (Evers et al., 2011).

2.4.3 Mercury in Environmental Media

Mercury monitoring in the Great Lakes basin has been ongoing; highlights of existing data are summarized below. Mercury has been detected in various environmental media, with the highest concentrations of mercury being found near urban and industrial areas.

2.4.3.1 In Air

Ambient mercury concentrations in the Great Lakes have decreased significantly since the 1970s (ITT, 2015). Atmospheric mercury concentrations have decreased about 2% per year since 2005 as measured in Canada's Experimental Lakes Area (west of Lake Superior). Wet deposition measurements from the North American Mercury Deposition Network follow these trends with fluxes decreasing about 1.6% per year since 1996 (ECCC and US EPA, 2017). Mercury emissions in the United States have decreased from an estimated 246 tons (223,167 kg) in 1990 to 52 tons (47,173 kg) in 2014 (US EPA, 2014) (**Figure 3**). In Canada, emissions have decreased from approximately 35,000 kg in 1990 to approximately 4,400 kg in 2015 (**Figure 4**) (ECCC, 2016b). Reductions in Canada are mostly due to one facility changing from pyrometallurgical to hydrometallurgical zinc production, closing a copper smelter in 2010 which represented the largest anthropogenic source of mercury in North America and, to a smaller extent, to increased emission control measures, improved PM emission controls and fuel switching (ECCC, 2018a).

A recent review of mercury in air reported by Cole et al. (2014) described long-term trends in mercury in air and precipitation in Canada. Declines were noted in total gaseous mercury and mercury in precipitation from the 1990s to early 2010 (Cole et al., 2014). Total gaseous mercury concentrations, with some identified exceptions, were generally 1.2 to 1.9 ng/m^3 throughout Canada. Wet deposition amounts averaged between 0.1 and 0.8 µg/m^2 month (Cole et al., 2014).

2.4.3.2 In Surface Water

Although reported present in trace amounts in Great Lakes surface waters, mercury remains a concern due to the potential for bioaccumulation and biomagnification in the food chain (ITT, 2015). Between 2003 and 2009, mercury concentrations in offshore surface waters of the Great Lakes were relatively low. Reported mercury concentrations ranged from 0.3 ng/L to 0.54 ng/L, significantly below the Canadian Water Quality Guidelines for Protection of Aquatic Life value of 26 ng/L (ITT, 2015). The lowest concentrations were identified in Lake Huron and Georgian Bay at 0.24 and 0.3 ng/L, respectively. Lake Superior and Lake Ontario concentrations were reported to be 0.35 ng/L, and Lake Michigan and Lake Erie had the highest concentrations at 0.49 ng/L and 0.54 ng/L, respectively (ITT, 2015).

Studies have identified a large decline (50-75%) in total aqueous mercury concentrations across the Great Lakes since 2000 (ITT, 2015). The significant decline in mercury concentrations has been attributed to concurrent declines in atmospheric deposition, reduced tributary loadings, and increased volatilization of gaseous mercury. However, the rate of decline in mercury concentration in near-shore (<100 meters in depth) waters is outpacing the rate of decline in mercury concentration in off-shore waters. This discrepancy has been identified for all Great Lakes, except for Lake Huron (ITT, 2015).

2.4.3.3 In Sediments

Sediment core samples from Lake Michigan suggest mercury influx peaked around the mid-1900s, then decreased after the 1970s, coinciding with establishment of the Clean Water Act. Evers et al. (2011) noted that the spike and eventual decline in mercury concentrations is consistent with trends in mercury emission and deposition in the Great Lakes. The consistent basin-wide decline in mercury sediment levels suggests that local, regional, and binational emission controls have been effective in decreasing the supply of mercury to the Great Lakes basin. The source contribution of mercury to sediments from wet deposition is shown in **Figure 5.**

Between 1970 and 2010, concentrations of mercury in surface sediments in open-lake areas of the Great Lakes ranged from 0.1 to > 1.0 µg/g (dry weight), with the highest concentrations found in Lakes Erie and Ontario, likely due to the influence of industrial activities (ITT, 2015). The spatial distribution of mercury in Great Lakes sediments is shown in **Figure 6**.

Mean mercury concentrations in Lake Erie and Lake Ontario sediment exceeded the Canadian Sediment Quality Guidelines for Protection of Aquatic Life probable effects level (0.486 µg/g dry weight) and threshold effects level (0.17 µg/g dry weight) for study data reported in 2003, 2005, and 2008 (ITT, 2015). In Lake Superior and the Georgian Bay, the mean mercury sediment concentration only exceeded the threshold effects level. In Lake Huron, the mean mercury sediment concentration was below both the probable effects level and threshold effects level (ITT, 2015). The higher mercury concentrations reported in the eastern Great Lakes are likely attributable to greater contributions from current local sources (e.g., electrical power generation) and higher deposition rates near the release locations (ITT, 2015).

There are a number of Areas of Concern (AOCs) throughout the Great Lakes that were identified as a result of mercury contaminated sediments (Thunder Bay, ON; Peninsula Harbour, ON; St. Clair River (ON and MI); St. Lawrence River (Cornwall, ON and Massena, NY); Buffalo, NY; Deer Lake, MI; Cuyahoga River, OH; Detroit, MI; Rouge River, MI; St. Louis River, MN). These sediment hot spots could be affecting the quality of benthos and fish for human consumption, and are being addressed through the implementation of local, multi-jurisdictional Remedial Action Plans.

2.4.3.4 In Biota

Monitoring efforts over the last forty years by ECCC showed dramatic declines in mercury levels in herring gull (*Larus argentatus*) eggs and multiple fish species (lake trout [*Salvelinus namaycush*], walleye [*Sander vitreus*], rainbow smelt [*Osmerus mordax*]) during the first three decades of monitoring. In the 2000s, the rate of mercury decline slowed, stopped, or even reversed for some monitored sites and species **(Figure 7)**. However, there has been an upward trend in mercury levels in two of the top predatory fish species, walleye and lake trout (ITT, 2015). Concentrations of mercury in top predatory fish measured by ECCC between 2008 and 2012 ranged from 233 ng/g wet weight in Lake Superior to 121 ng/g wet weight in Lake Erie (McGoldrick and Murphy, 2016). Concentrations recently observed and reported through U.S. Great Lakes Fish Monitoring Program are consistent, with concentrations of mercury generally between 110 to 250 ng/g across all lakes, except for Lake Superior, where elevated concentrations were observed, up to 415 ng/g (Carlson and Swackhamer, 2006; US EPA, 2014a).

It should be noted that over 97% of these recently observed sport fillet mercury concentrations are below the 0.5 µg/g (500 ng/g) target established under the 1987 Canada-United States Great Lakes Water Quality Agreement (Bhavsar et al., 2010; Zanaski et al., 2011; US EPA, 2014a). Since then, additional lower limits have been established by the US EPA (0.3 µg/g), states, and the province of Ontario (0.25 µg/g) for issuing consumption advisories. While it is evident that a large number of consumption advisories still exist on the basis of mercury concentrations, these are generally only minimally (i.e. 8 meals/month) to moderately restrictive (4 meals/month) (US EPA, 2014a).

Herring gull eggs from the Great Lakes have been monitored for persistent toxic chemicals since 1974 (ITT, 2015). From an egg survey conducted in 2009 across 15 sites in the Great Lakes basin, mercury concentrations ranged from 0.0064 µg/g wet weight at Chantry Island, Lake Huron to 0.246 µg/g wet weight at Middle Island, Lake Erie (ITT, 2015). However, the data indicate a decline in mercury concentrations at 14 of the 15 sites over 35 years (1974-2009) that ranged from 22.6 to 85.8%, with one site in Lake Erie showing an increase of 10.5% (ITT, 2015).

Based on analysis of data from 1999 to 2009, Zanaski et al. (2011) determined that average fish total mercury concentrations over this time period in the five lakes were significantly different from one another with the greatest concentrations in Lake Superior, then Huron, Michigan, Ontario and Erie. Evaluation of data from the mid-1970s to 2007 showed that concentrations of mercury generally declined over these three decades but that in recent years, concentrations across the Great Lakes have leveled off and increased slightly in Lake Erie (Bhavsar et al. 2010, International Joint Commission, 2015). A more recent analysis of combined Great Lakes data (except Lake Erie) showed a significant decreasing trend in the lake trout mercury concentrations between 2004 and 2015 with an annual decrease of 4.1% per year, consistent with the decline in regional atmospheric mercury emissions and water mercury concentrations (Zhou et al. 2017). Their analysis detected a breakpoint with a significant decreasing slope (−8.1% per year) before the breakpoint (2010), and no trend after the breakpoint. Examination of individual lakes showed that Lakes Superior and Huron, which are dominated by atmospheric mercury inputs and are more likely than the lower lakes to respond to declining emissions from areas surrounding the Great Lakes, have significant decreasing trends with rates between 5.2 and 7.8% per year from 2004 to 2015. These declining trends appear to be driven by decreasing regional atmospheric mercury emissions although they may be partly counterbalanced by other factors, including increasing local emissions, food web changes, eutrophication, and responses to global climate change. Lakes Michigan, Erie and Ontario may have been more impacted by these other factors and their trends changed from decreasing to non-decreasing or increasing in recent years.

Since 1993, levels of mercury in walleye from the west basin of Lake Erie have been increasing at 3.4% per year (SOLEC, 2017; see also Bhavsar et al., 2010; Blukacz-Richards et al., 2017; Lepak et al., 2015, 2018; McGoldrick, et al., 2016, 2018; Zhou et al., 2017). Recent studies of lake trout mercury concentrations in Lake Superior showed mercury levels in fish and other Great Lakes biota to be declining at a rate of approximately 6-7% per year since 2003 (Jeremiason, 2017). While there are currently no binational targets for mercury in fish, the observed concentrations are generally below levels of concern for the health of fish-consuming wildlife (500 ng/g wet weight) as established in the 1987 GLWQA (McGoldrick and Murphy, 2016). In Ontario, there is evidence of increasing mercury levels in fish based on analysis of tissue data for the period 2000 to 2012 but these results are predominantly for inland lakes in northern Ontario and shield lakes in southern Ontario (Ghandi et al. 2015).

2.5 High Level Summary of Risks

Once in the environment, mercury can convert to its highly bioaccumulative organic form, methylmercury, which is highly toxic and bioavailable when ingested. Elemental mercury, though also highly toxic and bioavailable when inhaled, is not typically found in sufficient concentrations in outdoor ambient air to cause concern (though indoor exposures can be high in industrial settings or where there has been a mercury spill. Methylmercury is an ecological risk to benthic (sediment-dwelling) organisms, fish, birds, and mammals because it bioaccumulates and biomagnifies as it moves up through the food chain. Adverse effects on wildlife include impaired development of early life stages, slower growth, endocrine and reproductive failures, hormonal and behavioral changes, and lethality (Scheuhammer, et al., 2007). There is also evidence that methylmercury may exhibit similar neurotoxicity endpoints in some species of wildlife as in humans (Basu and Head, 2010).

Methylmercury developmental neurotoxicity has constituted the basis for risk assessments and public health policies (Mergler, et al., 2007). Methylmercury is a human health risk because it is an easily absorbed and distributed neurotoxin that affects the central nervous system. Consumption of fish and other seafood is the primary pathway for human exposure to methylmercury. Elevated mercury concentrations are the cause for some fish consumption advisories in all the Great Lakes and there has been some evidence linking elevated mercury exposure in the Great Lakes basin to various health outcomes (Gilbertson, 2004, 2009; McCann, 2012). In Ontario's Great Lakes waters, mercury accounts for 25% of advisories for Lake Superior, 21% for Lake Huron, 40% for Lake St. Clair and the St. Clair River, 11% for Lake Erie, and 12% for Lake Ontario (**Figure 8**) (Evers et al., 2011). Mercury concentrations in the selected sizes of fish from the Great Lakes are now below 0.2 – 0.3 µg/g which allows for consumption advisories that are minimally (i.e., 8 meals per month) to moderately restrictive (i.e., 4 meals per month) for the general population (ITT, 2015). Updated fish consumption advisories are available on-line (Great Lakes Consortium for Fish Consumption Advisories, 2018; MOECC, 2018).

Mercury-induced toxicity affects the kidneys and central nervous system. At high-exposure levels, respiratory, cardiovascular, and gastrointestinal effects also occur (ASTDR, 1999; ATSDR, 2013). In pregnant women, methylmercury can cross the placenta into the fetus and accumulate in the fetal brain and other tissues. It can be passed through breast milk from the mother to infants and young children, who are especially vulnerable as their nervous systems are still developing (ASTDR, 1999).

Population-based exposure surveys in the United States have estimated that ~6-8% of childbearing aged women (16-49 years old) are at risk due to elevated methylmercury in their diets (Mahaffey, 2005). Despite mercury concerns, eating fish (especially fish low in mercury) is still recommended as part of a healthy diet, and breast-feeding is still considered the healthiest way to feed an infant (US FDA 2014; Ginsberg 2016; Raymond et al., 2017).

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

Working in partnership, the United States, Canada, the European Union, and individual countries have established strategies to significantly reduce mercury in mercury-containing products, promoted public awareness of adverse health and environmental effects, and proposed legislation to improve management of mercury use and waste.

3.1 United States

3.1.1 Existing Statutes and Regulations

A variety of regulations have been established at the federal, state, and local levels to limit the availability, use, discharge, emissions and overall number of mercury sources in the United States. In addition to federal mandates, some of the Great Lakes states, Tribes, and local jurisdictions (e.g., publicly owned treatment works [POTWs]) have issued more stringent regulations and processes to limit mercury releases. These statutes and regulations can embody U.S. Government implementation of the Minamata Convention on Mercury, including assisting with national reporting on the measures the United States has taken to implement the provisions of the Convention under Article 21.

Notable federal laws that apply to mercury in the United States include: the Mercury Export Ban Act of 2008 (MEBA), the Mercury-Containing and Rechargeable Battery Management Act, the Toxic Substances Control Act (TSCA), the Clean Air Act (CAA), the Clean Water Act (CWA), the Emergency Planning and Community Right-to-Know Act (EPCRA), the Resource Conservation and Recovery Act (RCRA), the Safe Drinking Water Act (SDWA), and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA or "Superfund"). In July 2017, the Effluent Limitations Guidelines and Standards for the Dental Category also came into effect. **Table 5** briefly summarizes these federal statutes as they pertain to mercury; additional information can be found at the provided websites.

Prior to 2016, the TSCA provided US EPA with authority to require reporting, recordkeeping and testing requirements, and restrictions relating to chemical substances and/or mixtures. On June 22, 2016, the Frank R. Lautenberg Chemical Safety for the 21st Century Act (Pub. L. 114-182, 130 Stat. 448; Lautenberg Act), amended the TSCA. Provisions in the Act that are specific to mercury and mercury compounds include:

- **The ban on exporting elemental mercury, previously initiated under MEBA, now includes mercury compounds.** The US EPA published a notice of this statutory prohibition in the Federal Register in August 2016: https://www.regulations.gov/docket?D=EPA-HQ-OPPT-2016-0411.

- **Provisions on long-term storage of elemental mercury were amended.** The deadline for the U.S. Department of Energy to open a facility for storage of elemental mercury was extended to 2020.

- **US EPA is required to publish an inventory of mercury supply, use, and trade in the United States and must update this inventory every three years.** The US EPA published its initial inventory report in the Federal Register in March 2017: https://www.regulations.gov/docket?D=EPA-HQ-OPPT-2017-0127

- **US EPA is required to publish a reporting rule to assist in the preparation of the mercury inventory.** The rule was published June 2018 and requires manufacturers to report on their use of mercury and mercury compounds: https://www.regulations.gov/document?D=EPA-HQ-OPPT-2017-0421-0099.

The United States has also made progress on regulatory efforts to decrease mercury emissions from source categories. Under the CAA, the US EPA established a rule known as the Mercury and Air Toxics Standards (MATS), which includes national emission standards for mercury and other hazardous air pollutants for new and existing coal- and oil-fired power plants in the United States. All covered facilities are currently required to achieve these emission limits. MATS was published in 2012 and EPA provided the maximum 3-year compliance period, so sources were generally required to comply no later than April 16, 2015. MATS is estimated to prevent about 90 percent of the mercury in coal burned in power plants from being emitted to the air (US EPA, 2017d). MATS includes technology-based emissions limitation standards based on Maximum Achievable Control Technology (MACT) for mercury and other toxic air pollutants from power plants. More specific information about MATS can be found at the EPA's Mercury and Air Toxics Standards website.

US EPA also has established MACT standards to control mercury emissions from other industry sectors, including municipal waste combustors, medical waste incinerators, sewage sludge incinerators, gold ore processing plants, Portland cement production facilities, electric arc furnace steelmaking facilities, mercury cell chlor-alkali facilities, and industrial boilers. Both new and existing sources must comply with the appropriate standards. Each of these standards includes requirements for testing, monitoring or work practices to establish initial and on-going compliance, as well as recordkeeping and reporting. Details for these standards can be found at Clean Air Act Guidelines and Standards for Waste Management and National Emission Standards for Hazardous Air Pollutants (NESHAP). Since the primary source of mercury to the lakes is atmospheric deposition that is either directly deposited to the lake or flows into the lakes through run-off/stream flow, these actions that address mercury emissions in the United States help considerably toward reducing and preventing mercury loadings to these waterbodies.

3.1.2 Pollution Prevention Actions

The US EPA is responsible for implementing the Pollution Prevention (P2) Act of 1990, which involves reducing or eliminating waste at the source by modifying production processes, promoting the use of nontoxic or less toxic substances, implementing conservation techniques, and reusing materials rather than putting them into the waste stream. In many cases, individual states have been leaders in banning mercury in products, in organizing mercury collections, and in working with small businesses to improve handling of mercury. **Table 6** presents findings from a 2011 survey of mercury activities by individual Great Lakes state agencies. Each of the Great Lakes states has additional mercury programs, beyond federal regulations. Each state has one or more programs to assist in the management of mercury-containing products. In addition, all states participate in the National Vehicle Mercury Switch Recovery Program and individually disseminate Fish Consumption Advisories to their citizens (Quicksilver Caucus, 2012).

The US EPA is charged under the P2 Act to integrate P2 policy into its environmental programs, including air, water, toxics, and hazardous waste, as well as to promote P2 practices and source reduction approaches at other federal agencies. The US EPA established the National Vehicle Mercury Switch

Recovery Program[3], a partnership agreement with the “Big Three” auto manufacturers (i.e., Ford, GM and Chrysler) and junkyards/recyclers, scrapyard shredders, steel mills, and states, which provides for the removal of mercury switches from junked cars before they are shredded and sold as scrap metal to steel mills. Since 2006, the national program has collected more than 4.5 million switches. In the Great Lakes states, nearly 2.3 million switches have been recovered, equating to 9,225 pounds of collected mercury (US Ecology, 2017).

The US EPA's Pollution Prevention Strategic Plan identifies opportunities for the P2 program to help reduce emissions of greenhouse gases, the use of hazardous materials, and the use of natural resources while working toward a greener and more sustainable economy. The P2 Program Strategy for Electronics addresses the problem of environmental impacts of electronics products, from manufacturing processes through use to end-of-life (recycling), all factors that require the use of energy and may result in significant greenhouse gas and other emissions, including mercury from coal-fired energy generation (US EPA, 2010).

3.1.3 Risk Management Actions

The Great Lakes Restoration Initiative (GLRI) is a United States initiative launched in 2010 to provide funds for accelerating efforts to protect and restore the Great Lakes ecosystem. The GLRI is a federal agency coordination of the Great Lakes Interagency Task Force and the Great Lakes Regional Working Group, led by the US EPA. One of the five major areas of the GLRI is Toxic Substances within Areas of Concern (AOCs), and mercury is one of the toxic substances under this focus area. Work accomplished during the GLRI’s first five years is described in the Report to Congress and the President (Great Lakes Interagency Task Force, 2015). Between 2004 and 2015, an estimated 4 million cubic yards (3 million cubic meters) of contaminated sediments in United States AOCs were remediated. The remediated sediments contained mercury and other contaminants of concern (US EPA, 2016a). As a result of remediation efforts during GLRI, three AOCs were removed from the list of areas designated as the most contaminated sites on the Great Lakes.

3.1.4 Monitoring, Surveillance and Other Research Efforts

Environmental monitoring and surveillance of Great Lakes have been conducted through several United States parties and coordinated with Canadian program activities to ensure basin-wide coverage and to minimize duplication of efforts. 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. In addition, GLNPO supports work on toxic chemicals, including mercury, with other partners via grants, interagency agreements, and collaborations to address chemical issues as they relate to human health. The following are highlighted programs being done to acquire mercury data within the United States:

- The Great Lakes Open Lakes Trend Monitoring Program began as a component of the Great Lakes Fish Monitoring and Surveillance Program. The program has monitored contaminant trends in fish of the Great Lakes since its inception in the late 1970s. There are 10 permanent monitoring stations in the program. Fish samples are collected at five stations per year, one in each Great Lake. The program aims to collect 50 top predators to be analyzed as 10 five-fish composites, limited to a strict size range, per station each year. Total mercury is one of the chemical parameters analyzed in the fish tissue.

[3] Operated by End of Life Vehicle Solutions (ELVS), a nonprofit organization.

- National Atmospheric Deposition Program/Atmospheric Mercury Network (AMNet) operates 20 sites in the United States, with three AMNet sites located in the Great Lakes basin, which monitor the atmospheric concentrations of speciated mercury fractions, gaseous elemental mercury, gaseous oxidized mercury, and particulate-bound mercury. These data have supported dry deposition estimates, emission regulatory assessments, model evaluation, and long-term trends (NADP, 2011).

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. Mercury monitoring data from various programs are tracked through three primary databases: Great Lakes Environmental Database (GLENDA), Science in the Great Lakes (SiGL) Mapper, and the Toxics Release Inventory (TRI) Program. The following monitoring networks, programs, and data repositories include collection of mercury data in the Great Lakes basin:

- Much of the United States data collected has been placed in GLENDA, which collects and stores 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, 2016b).

- SiGL Mapper is an additional searchable meta 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, 2015b). These databases enable researchers to use historic data from across the basin to solve complex chemical, biological, and physical relationships that might lead to more advanced methods for pollution identification and remediation actions.

- The TRI database is the United States' Pollutant Release and Transfer Registry (PRTR) (US EPA, 2014b). The TRI database tracks releases, disposals, and transfers of mercury (and its compounds) from industrial sources that exceed applicable thresholds. Under EPCRA of 1986 all manufacturing or processing facilities that use mercury are required to report the annual quantities of hazardous or toxic chemicals used, as well as pollution prevention and recycling information to the TRI database. This database, maintained by the US EPA, is publicly available and intended to inform the public and help increase the public's knowledge of and access to information on chemicals at individual facilities, their uses, and releases into the environment. States and communities, working with facilities, can use the information to improve chemical safety and protect public health and the environment (US EPA, 2014; US EPA, 2015a).

3.1.5 United States Guidelines and Standards

In 1995, US EPA published regulations affecting the Great Lakes, "Final Water Quality Guidance for the Great Lakes System; Final Rule" (40 CFR Parts 9, 122, 123, 131, and 132) (the Guidance). These rules include recommended water quality criteria for mercury to protect humans and wildlife from exposure to mercury through consumption of contaminated aquatic organisms. The published human health value for the Great Lakes system is 1.8 ng/L (see 40 CFR 132, Table 3, 1.8 x 10 -3 µg/L) and the published criterion to protect piscivorous wildlife is 1.3 ng/L (see 40 CFR 132, Table 4, 1.3 x 10 -3 µg/L). States in the Great Lakes basin are required to adopt criteria that are consistent with (as protective as) those published in the Guidance for surface waters under their jurisdiction within the Great Lakes basin.

Table 7 lists US EPA and United States Food and Drug Adminsitration (US FDA) standards and recommendations in effect for mercury in blood, environmental waters, drinking water, groundwater, and fish. There are no ambient air quality recommendations. An additional resource for Great Lakes Basin water quality standards is the Great Lakes Initiative (GLI) Clearinghouse. The GLI Clearinghouse is a central resource for developing water quality standards in the Great Lakes watershed. It contains information on criteria, toxicity data, exposure parameters and other supporting documents. It can be used to help establish water quality criteria, permit discharge limits, Total Maximum Daily Loads, Remedial Action Plans and Lakewide Management Plans.

3.2 Canada

3.2.1 Existing Statutes and Regulations

In February 2017, Canada introduced comprehensive restrictions on the exports of mercury. The *Export of Substances on the Export Control List Regulations*, under CEPA 1999, restrict the export of mixtures containing elemental mercury at a concentration of 95% or more by weight, with some exemptions, which are in line with the Minamata Convention.

On February 11, 2017 and pursuant to subsection 54(4) of CEPA1999, the Minister of Environment and Climate Change published a *Notice of the Code of Practice for the Environmentally Sound Management of End-of-life Lamps Containing Mercury* in the *Canada Gazette,* Part 1 (ECCC, 2017b). The Code of Practice is designed to encourage collectors, transporters, and recyclers to incorporate best practices in their management of end-of-life mercury-containing lamps to prevent releases of mercury to the environment. Recognizing that northern and remote regions often face unique challenges that can make it difficult to collect and manage end-of-life mercury-containing lamps, the Code includes additional information on management options that can be used to facilitate the implementation of best practices.

The *Products Containing Mercury Regulations,* which came into force in 2015 prohibit the manufacture and import of products containing mercury or any of its compounds, with some exemptions for essential products that have no technically or economically viable alternatives (e.g., certain medical and research applications, and dental amalgam) (ECCC, 2014). In the case of lamps, rather than introducing a prohibition, the Regulations limit the amount of mercury contained in fluorescent and other types of lamps. The objective of the Regulations is to reduce releases of mercury from products used in Canada to the lowest level that is technically and economically feasible. In February 2018, Canada published a consultation document on proposed amendments to the *Products Containing Mercury Regulations* that aim to fully align Canada with requirements respecting products under the Minamata Convention on Mercury.

The *National Strategy for Safe and Environmentally Sound Disposal of Lamps Containing Mercury Act* was enacted in June 2017 and required the Minister of the Environment to develop a National Strategy for Safe and Environmentally Sound Disposal of Lamps Containing Mercury. The National Strategy was developed in collaboration with provinces, territories, other governments, and other stakeholders, and was published in 2019. The strategy recommends actions to engage and mobilize public, private, and non-profit sectors to ensure that lamps containing mercury are diverted in an environmentally sound manner and that transition to mercury-free lamps occurs as soon as feasible.

3.2.2 Pollution Prevention Actions

The *Notice Regarding Pollution Prevention Planning in Respect of Mercury Releases from Dental Amalgam Waste* was published in 2010 by ECCC. This notice targets dental facilities that have not implemented all of the best management practices set out in the Notice and outlines the requirements to prepare and implement pollution prevention plans for mercury releases from dental amalgam waste.

The *Notice Regarding Pollution Prevention Planning with respect to Mercury Releases from Mercury Switches in End-of-life Vehicles Processed by Steel Mills* was published in 2007 as a Final Notice under Part 4 of CEPA. The Notice targets vehicle manufacturers and steel mills, requiring the preparation and implementation of a pollution prevention plan for the management of mercury switches from end-of-life vehicles, to reduce the release of mercury to the environment (ECCC, 2007). The Notice was completed in December 2017.

In Ontario, Toxics Reduction Planning for Mercury was incorporated into the Toxics Reduction Act in 2009. Regulated facilities under the Toxics Reduction Act must perform substance accounting and prepare toxics reduction plans if mercury is used over the 5kg threshold at the facility. The objective of the toxics reduction plan is to reduce the use and creation of mercury, so that it reduces the potential for releases to the environment. The toxic substance accounting and preparation of the toxics reduction plan is mandatory, however the implementation of the plans is voluntary, allowing each facility an opportunity to move forward at a rate that best reflects its unique economic and operational circumstances.

In 2018, Canada launched the Great Lakes Protection Initiative (GLPI), a funding program designed to help deliver on commitments under the GLWQA. One of the priority areas under GLPI is the reduction of releases of CMCs (including mercury) to the Great Lakes from Canadian sources through projects that support beyond compliance measures and innovative approaches.

3.2.3 Risk Management Actions

The *Risk Management Strategy for Mercury* provides a comprehensive and consolidated description of the Government of Canada's progress to date in managing the risks associated with mercury. It identifies the objectives, priorities, existing and anticipated actions targeting various industrial sectors, and monitoring programs in place to address the ongoing risks associated with mercury (ECCC and Health Canada, 2010). The ultimate environmental and human health objective for mercury in Canada is minimizing, and where feasible, eliminating anthropogenic emissions and releases to the environment and minimizing mercury exposure to Canadians.

Following publication of the Strategy, Canada continued to move forward with both domestic and international actions to further reduce mercury. In 2020, Canada published the report Evaluation of the Effectiveness of Risk Management Measures for Mercury which assessed whether the risk management actions taken for mercury were effective in meeting the objective outlined in the risk management strategy. The report concluded that continued sustained action on mercury is needed to further protect the health of Canadians and their environment from the risks of mercury and committed Canada to continue its efforts in four main areas: monitoring, managing risks associated with mercury, communicating with the public and engaging internationally.

The *Risk Management Strategy for Mercury-containing Products*, published in 2006, provided a framework for the development of controls to manage mercury-containing products and the environmental effects of mercury used in products (ECCC, 2006). Several strategies were proposed, and many were later integrated into the *Products Containing Mercury Regulations,* such as:

- Prohibition of mercury-containing products for which mercury-free alternatives exist
- Prohibition of mercury use in new products, not currently available on the Canadian market, with possible exemptions

- Mercury content limits in products for which mercury-free alternatives do not exist (novelty items excluded)
- Labelling requirements for mercury-containing products.

Remediation of mercury-contaminated sediment was undertaken at the Peninsula Harbour Area of Concern in 2012 and the St. Clair River Area of Concern from 2002 to 2004.

3.2.4 Compliance Promotion and Enforcement

To achieve greater compliance with risk management tools, both compliance promotion activities and enforcement measures are used. The goal of compliance promotion is to increase awareness and voluntary compliance with regulatory and non-regulatory instruments in an effort to limit harm to the environment and human health, with the aim to reduce the need to take enforcement action. Enforcement is done in a fair, predictable and consistent manner. Enforcement activities are conducted in accordance with the Compliance and Enforcement policies, which are available online. ECCC carries out compliance promotion and risk-based enforcement activities for applicable mercury risk management tools, including those for the Products Containing Mercury Regulations.

3.2.5 Monitoring, Surveillance, and Other Research Efforts

Monitoring and measurement for mercury is conducted in water, sediment, air, precipitation, wildlife (including fish and herring gull eggs), and human biomonitoring at sites across Canada, including in the Great Lakes basin. Measurements are collected by ECCC through several different initiatives, including the national Chemicals Management Plan (Government of Canada, 2016). An in-depth assessment of surface waters, surface sediments, and sediment cores is conducted annually and on a rotational basis for each of the Canadian Great Lakes. Additional water and sediment samples may also be collected from the connecting channels of the assessed lake.

Additional monitoring is conducted under regional Great Lakes-specific monitoring and surveillance programs for air, precipitation, herring gull eggs, fish, sediment, and water. The following list highlights select programs being done to acquire mercury data within Canada:

- Human Biomonitoring. In Canada, there are currently no routine Great Lakes-specific human biomonitoring programs to monitor human exposure to persistent chemicals. Therefore, nationwide studies and results of individual epidemiological studies undertaken in the Great Lakes are used to evaluate mercury concentrations in humans in the Great Lakes basin. The Canadian Health Measures Survey (CHMS), initiated in 2007, is a national survey led by Statistics Canada, in partnership with Health Canada and the Public Health Agency of Canada and includes assessment of blood, urine, and hair collected from survey participants for a wide variety of environmental chemicals (Statistics Canada, 2016). The CHMS has recently examined the mean blood concentrations of methylmercury in Canadians and the First Nations Biomonitoring Initiative (FNBI) examined the concentration of inorganic mercury in the blood of Canadian First Nations populations in 2011 (AFN, 2013). Samples were assessed for total mercury in the blood and inorganic mercury in urine. The coefficient of variation for the blood samples was too high to allow for comparison. No comparison could be made between the urine sample sets as more than 40% of the samples were below the limit of detection. However, findings in the urine samples did lead the authors to believe that there may be a greater exposure to inorganic mercury in the FNBI population than the CHMS population, but further investigation is required (AFN, 2013; Statistics Canada, 2016).

- The Fish Contaminants Monitoring and Surveillance Program (FCMSP) began in 1977 with a focus on monitoring activities in the Canadian waters of the Great Lakes as part of GLWQA. Canada's program activities have been coordinated with those of the United States to ensure basin-wide coverage and to minimize duplication of efforts. The program targets predatory and long-lived fish species that bioaccumulate contaminants. Forage fish, benthos, and plankton are also sampled. Mercury is one of the contaminants of interest analyzed in tissues for the FCMSP.

- The Ontario Ministry of Environment, Conservation and Parks (MECP) has monitored mercury in a variety of sport and forage fish in Ontario, Canada since the 1970s in partnership with Ontario Ministry of Natural Resources Forestry (OMNRF) and various other agencies/ institutes. Results are used to produce the Guide to eating Ontario Fish, as well as to analyze trends. In addition, the province has multiple monitoring and surveillance programs that track mercury and methyl-mercury in sediment, drinking water, nearshore waters and other media.

- Canadian Atmospheric Mercury Measurements. Canada currently has one long-term air monitoring station for mercury in the Great Lakes region located in Egbert, Ontario, north of Toronto. Since 1994, considerable atmospheric mercury monitoring and research has taken place across Canada through both ongoing networks and independent research programs. Most monitoring began as independent research programs to measure total gaseous mercury (TGM) in the early 1990s. Realizing the benefits of a community, researchers joined forces to create the Canadian Atmospheric Mercury Measurement Network (CAMNet) in 1994. CAMNet was operated by ECCC from 1994 to 2007, with between 7 and 15 sites across Canada. Later, some of these sites were transferred to the Canadian Atmospheric and Precipitation Monitoring Network (CAPMoN), which still operates these sites today, and to other networks. The remainder of the currently operated ECCC sites are either part of the Northern Contaminants Program (NCP) or are run as part of ECCC measurement programs. As of 2017, these individual programs have been consolidated and fall under Environment and Climate Change Canada – Atmospheric Mercury Monitoring or ECCC-AMM. Currently, there are 12 sites in Canada that collect continuous TGM. As of January 2017, The ECCC-AMM monitors TGM at 12 sites, total particulate mercury (TPM) (termed speciated atmospheric mercury) at 6 sites and wet deposition at 5 sites.

- The Canadian Mercury Science Assessment (CMSA) was the first comprehensive scientific evaluation and synthesis of mercury in the Canadian environment. The Clean Air Regulatory Agenda (CARA) Mercury Science Program was developed in 2007 to further understand the status of mercury in the Canadian environment and the impact of mercury on Canadian ecosystems and population, and to establish the scientific knowledge base to support regulatory decision-making for mercury. The CMSA was a key outcome of that program. The final document included contributions from more than 230 researchers. This scientific assessment of mercury in Canada has led to the recognition of several detailed priority gaps of knowledge, and has provided scientific recommendations for focus areas and future research, including the integration of mercury impacts on human health, wildlife, and the ecosystem (ECCC, 2016a).

The report Evaluation of the Effectiveness of Risk Management Measures for Mercury concluded that data obtained through Canada's various human biomonitoring programs are essential to determine trends in Canadians' exposure to mercury and that data obtained through environmental monitoring and surveillance activities are necessary to determine spatial and temporal trends of mercury in key environmental media. The report noted that monitoring is critical to measuring performance for risk management actions and ongoing monitoring is important since changes in emissions and ecosystem shifts are causing changes in the trends of mercury levels in the environment.

Mercury monitoring and release data results from various programs are centralized in the Canadian Federal Government Open Data Portal. This portal includes data held by the National Atmospheric Chemistry Database (NAtChem) and the National Pollutant Release Inventory (NPRI).

- NAtChem is a data archival and analysis facility operated by the Science and Technology Branch of ECCC. The purpose of the NAtChem database is to enhance atmospheric research through the archival and analysis of North American air and precipitation chemistry data, including results of research investigations into the chemical nature of the atmosphere, atmospheric processes, spatial and temporal patterns, source-receptor relationships, and long-range transport of air pollutants. The NAtChem Database contains air and precipitation chemistry data from many major regional-scale networks in North America, as well as several major short-term special studies. Contributing networks to NAtChem generally must operate for a period of at least two years, have wide area coverage, and include regionally representative sites (rural and background). The NAtChem Database consists of several smaller databases, one of which contains mercury data. The mercury database contains three types of atmospheric mercury measurements: mercury in precipitation, total gaseous mercury, and mercury speciation in aerosols and gases (ECCC, 2017a).

- NPRI, Canada's PRTR, has tracked releases, disposals, and transfers of mercury (and its compounds) from industrial sources since the NPRI program's inception in 1993. From 1993 to 1999, facilities were required to report mercury once they met the standard NPRI reporting threshold (this threshold was originally based on the thresholds used by the United States TRI). More specifically, during this period facilities were required to report their annual releases, disposals, and transfers of mercury to the NPRI if they met the following reporting criteria:
    - The facility had the equivalent of 10 or more full-time employees; and
    - They manufactured, processed, or otherwise used (MPO) at least 10 tonnes of mercury and its compounds at a concentration of at least 1% by weight.

  Starting in 2000, the threshold for the reporting of mercury to the NPRI was lowered to 5 kg MPO at any concentration. According to the data reported to the NPRI for 2015, Canadian facilities in the vicinity of the Great Lakes released a total of 605 kg of mercury (and its compounds); the majority of these releases were reported as releases to the atmosphere. In addition, 34,678 kg of mercury was reported as disposals and 6450 kg were transferred off-site for recycling within this region. In the area surrounding the Great Lakes, the largest mercury releases were reported by facilities in the following sectors: iron and steel mills and ferro-alloy manufacturing, cement manufacturing, sewage treatment, gypsum product manufacturing, non-ferrous metal (except aluminum) smelting and refining, and fossil-fuel electric power generation (ECCC, 2016c).

3.2.6 Canadian Environmental Quality Guidelines and Standards

Canadian Environmental Quality Guidelines (CEQGs) for Mercury have been developed by the Canadian Council of Ministers of the Environment (CCME), which consists of federal, provincial, and territorial environment ministers. CEQGS are nationally endorsed, science-based goals for the quality of atmospheric, aquatic, and terrestrial ecosystems. CEQGS are benchmarks that are recommended as levels that should result in negligible risk to biota, their functions, or any interactions that are integral to sustaining the health of ecosystems. **Table 7** presents CEQGs for mercury in various media.

The Canada-Wide Standards (CWS) Program is a framework under which federal, provincial, and territorial environment ministers address key environmental protection and health risk reduction issues that require common environmental standards across the country. CWS are developed to achieve nationally unified environmental objectives while allowing participating jurisdictions to implement complementary plans in a way that suits their individual circumstances. The CWS are developed by the CCME. CWS are based on science, but also take into consideration technical feasibility and socio-economic factors. Generally, the CWS consist of a numeric limit and a timeline that sets a deadline for achieving the limit. Implementation plans, progress monitoring, and public reporting are also important aspects of the CWS process. With respect to mercury, CWS have been developed for mercury emissions from base-metal smelters, waste incinerators, coal-fired power plants, mercury-containing lamps, and dental amalgam waste. Brief descriptions of the CWS for mercury emissions are below:

- *Base Metal Smelting.* For base metal smelting facilities, a two-part standard was established to address both existing and new/expanding operations (CCME, 2000). New and expanding facilities should be equipped to meet a guideline of 0.2 g mercury per tonne of finished zinc, nickel, or lead, or 1 g mercury per tonne of finished copper. As of 2009, all but one base metal smelting facilities met the CWS emissions goal of 2 g mercury/tonne of finished metals (CCME, 2010). The single facility that did not meet this standard was not located within the Great Lakes basin and was closed in 2010.

- *Waste Incineration.* Under the CWS, limits for the concentration of mercury in exhaust gas were established for various types of waste incinerators. Larger (processing greater than 120 tonnes of waste per year) facilities must conduct annual stack tests to confirm that the target concentration is achieved. Smaller facilities must make determined efforts, such as an ongoing review of waste diversion options and/or emission control upgrades, to reduce mercury emissions (CCME, 2000). The CWS for hazardous waste incinerators was to achieve a maximum concentration of exhaust gases of 50 $\mu g/Rm^3$ by 2003. As of 2007, all six hazardous waste incinerators in Canada were in compliance, including the five facilities in Ontario (CCME, 2007).

- *Coal-Fired Electric Power.* CWS consists of two sets of targets: (1) provincial caps on mercury emissions from existing coal-fired electric power generating plants, with the 2010 provincial caps representing a 60% national capture of mercury from coal burned, or 70% including recognition for early action; and (2) capture rates or emission limits for new plants, based on best available control technology, effective as of 2006 (CCME, 2000). In 2014, the capture rate of mercury from coal-generated power plants was 67%, exceeding the CWS goal (CCME, 2016). From 2003 to 2014, total mercury emissions from coal-fired electric plants decreased by more than 75% (CCME, 2016). In January 2017, the Government of Canada released the Pan-Canadian Framework on Clean Growth and Climate Change and indicated its intention to phase out coal-fired electricity generation to cleaner sources by 2030. To deliver on this intention, the Government of Canada's *Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations* (2012) and its announced amendments (2016), are expected to generate co-benefits of reducing releases of metals, including mercury, to varying degrees depending on the actions taken by the facilities (e.g., closure, installation of carbon capture and storage technologies, or transition to low-emission fuels). In Ontario, coal-fired electricity production ceased in 2014 resulting in zero release of mercury in the province and into the Great Lakes from locally situated coal-fired plants (CCME, 2016).

- *Mercury-containing Lamps.* The CWS for Mercury-containing Lamps takes a pollution prevention approach by calling for a reduction in the average mercury content of lamps sold in Canada. From a 1990 baseline, the numeric target is a 70% reduction by 2005 and a total reduction of 80% by 2010 (CCME, 2001). By 2004, the average mercury content per lamp had reduced by 73.5% from the 1990 baseline, exceeding the 2005 CWS target (CCME, 2007). Recycling projects funded by the Ontario Ministry of the Environment collected and recycled more than 14,000 lamps in 2007, capturing more than 400 grams of mercury from within Ontario (CCME, 2007).

- *Dental Amalgam Waste.* The goal of the CWS for Dental Amalgam Waste is to reduce national mercury releases from dental amalgam waste by 95% by 2005 from a 2000 baseline. This CWS promotes the use of best management practices, such as the installation of ISO-certified amalgam traps to achieve the target. It led to the signing of a Memorandum of Understanding by ECCC and the Canadian Dental Association (Canadian Minister of the Environment and Canadian Dental Association, 2002), which focuses on reducing mercury releases from dental facilities. By 2007, 70% of dentists across Canada were using ISO separators, allowing for a 57% reduction in mercury reaching dental wastewaters (CCME, 2007). By 2008, 100% of Ontario dentists had installed amalgam separators to capture waste mercury (US EPA and Canada, 2009). Since by 2007 the 95% target set out in the CWS was not met, Environment and Climate Change Canada took action to achieve the target using pollution prevention planning, through the publication in 2010 of the notice regarding *Pollution Prevention Planning in Respect of Mercury Releases from Dental Amalgam Waste*.

3.3 Binational Actions

3.3.1 Great Lakes Binational Toxics Strategy

The Great Lakes Binational Toxics Strategy (GLBTS) was a binational P2 endeavor from 1997 to 2007 that focused on the virtual elimination of mercury and mercury-containing compounds, among other persistent, bioaccumulative, and toxic chemicals. The Strategy outlined a four-step process for addressing recognized knowledge gaps regarding the Great Lakes basin: (1) gather information; (2) analyze current regulations, initiatives, and programs that manage or control substances; (3) identify cost-effective options to achieve further reductions; and (4) implement actions to work toward the goal of virtual elimination (US EPA and ECCC, 1997).

3.3.2 Lakewide Action and Management Plans

Additional binational mercury pollution prevention actions have been initiated through LAMP programs for each Great Lake. LAMPs are plans of action to assess, restore, protect, and monitor the ecosystem health of each Great Lake (US EPA, 2004; US EPA, 2016d). As an example, the Lake Superior Zero Discharge Demonstration Program (ZDDP) was established in 1991 by the Lake Superior Binational Program (LSBP) with a goal of eliminating nine persistent, bioaccumulative, and toxic pollutants, including mercury, from Lake Superior by 2020 (Lake Superior Partnership, 2016). Under the Lake Superior ZDDP, an inventory of mercury (equipment and waste containing mercury) in the Lake Superior basin has been updated approximately every 5 years since 2000. Other LAMPs are in the process of reviewing their monitoring priorities, which may include CMCs in the future.

3.3.3 Great Lakes Regional Collaboration

The Great Lakes Regional Collaboration (GLRC) was a cooperative effort between the Governors and Premiers of the Great Lakes States and Provinces. Members of the GLRC include the Great Lakes Interagency Task Force, the Council of Great Lakes Governors, the Great Lakes and St. Lawrence Cities

Initiative, the Great Lakes Native American Tribes, and the Great Lakes Congressional Task Force. The GLRC has produced two key strategies for Mercury:

- *Great Lakes Mercury in Products Phase Down Strategy (2008).* Great Lakes Mercury in Products Phase Down Strategy was developed in response to the GLRC Strategy to Restore and Protect the Great Lakes. The phase down strategy established timelines for full phase-outs of mercury-added products by 2015.

- *Great Lakes Mercury Emission Reduction Strategy (2010).* The Great Lakes Mercury Emission Reduction Strategy was developed in response to the GLRC Toxic Pollutants Initiative, which called for the development of a basin-wide mercury emission strategy designed to phase out the use of mercury and provide for mercury waste management. The Strategy was not intended to be a comprehensive summary of actions to reduce mercury releases to the Great Lakes; rather, it addressed mercury air emissions with a primary goal to reduce mercury emissions from new and existing sources whose mercury emissions have not been regulated, and from sources where regulations have been implemented but additional cost-effective reductions can be achieved. The Strategy was finalized in December 2010 and presented 34 recommendations for reducing mercury emissions in seven source sectors, as well as cross-cutting strategies and actions to track progress of implementation (GLRC, 2010). By 2014, approximately 75% of the recommendations had been completed or were continuing across the eight Great Lakes States (GLRC, 2014).

3.3.4 National Atmospheric Deposition Program/Mercury Deposition Network

The Mercury Deposition Network (MDN) is a long-term mercury wet-deposition monitoring network of the National Atmospheric Deposition Program (NADP). NADP is a cooperative program between federal, state, provincial, academic institutions, indigenous peoples, and private organizations. MDN provides a long-term record of total mercury concentration and deposition in precipitation across the United States and Canada. The MDN began measuring total mercury in precipitation in 1996. It now includes more than 100 sites. All MDN sites follow standard procedures and have uniform precipitation chemistry collectors and gages to allow for direct comparison between sampling sites. While total mercury in precipitation is measured at all locations, methylmercury is monitored at select sites (NADP, 2011).

3.3.5 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. 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, when appropriate.

3.3.6 State of the Great Lakes Reporting

Between 1994 and 2011, the US EPA and ECCC coordinated reporting efforts under the State of the Lakes Ecosystem Conferences (SOLEC) (ECCC and US EPA, 2011). Since then, the SOLEC conference has been replaced with scientific confirmation webinars to review a triennial assessment and report from the governments of Canada and the United States (ECCC and US EPA, 2017). These reports provide decision-makers and scientists the opportunity to receive comprehensive and current information on the state of the Great Lakes through three main elements:

- Interactive scientific webinars convened triennially for Great Lakes stakeholders to review assessments and reports and provide additional information or interpretation.
- State of the Lakes reports incorporating a suite of indicators of the status and trends of Great Lakes ecosystem components developed by Great Lakes agencies, organizations, and other stakeholders as the basis for the triennial assessments.
- A comprehensive State of the Great Lakes technical report based on findings from the indicators.

3.4 International

Both the United States and Canada participate in a number of initiatives and partnerships established at the international level to limit the availability, use, release, and overall number of mercury sources.

3.4.1 United Nations Economic Commission for Europe, Convention on Long-Range Transboundary Air Pollution

The 1998 Aarhus Protocol on Heavy Metals to the Convention on Long-range Transboundary Air Pollution (LRTAP) aims to reduce emissions from industrial sources and products for three harmful metals: mercury, cadmium, and lead. Stringent limits were established for emissions from stationary sources and best available techniques were suggested for use. The protocol proposed management measures for mercury in batteries, electrical components, measuring devices, fluorescent lamps, dental amalgam, pesticides, and paint (ECE, 2014; UNECE, 2017). In 2012, the protocol was amended to encourage ratification from UNECE countries with economies in transition.

3.4.2 United Nations Environment Program, Minamata Convention on Mercury

The Minamata Convention on Mercury (Minamata Convention) currently has 128 signatory countries and as of April 1, 2021 has been ratified by 129 Parties (http://mercuryconvention.org/). The United States and Canada are both Parties, with the United States having joined in 2013 and Canada in 2017. The Convention is the first new global convention related to environment and health in close to a decade. Among other agreements and efforts, the Minamata Convention builds upon the 1998 Protocol on Heavy Metals to raise the profile of mercury to a global level (UNECE, 2017). The Convention covers the entire lifecycle of mercury pollution resulting from human activities and includes commitments by Parties to prohibit new mercury mines, phase-out existing ones, prohibit a number of mercury-containing products and mercury processes, reduce or eliminate the use of mercury in artisanal and small-scale gold mining, and reduce mercury emissions and releases.

The Convention entered into force in August 16, 2017, and the first meeting of the Conference of the Parties (COP1) to the Minamata Convention took place in September 2017 in Geneva, Switzerland. Parties to the Convention will have committed to the implementation of specific measures to control mercury pollution:

- Control, and where feasible reduce mercury air emissions from coal-fired power plants, coal-fired industrial boilers, certain non-ferrous metals smelting and roasting operations (lead, zinc, copper and industrial gold), waste incineration, and cement clinker production, including use of best available techniques and best environmental practices for new and substantially modified sources.

- Phase out mercury in listed products (e.g., batteries, switches, lights, cosmetics, pesticides, and measuring devices) and create initiatives to reduce the use of mercury in dental amalgam.
- Phase out or reduce the use of mercury in manufacturing processes such as chlor-alkali production, vinyl chloride monomer production, and acetaldehyde production.
- Address the supply and trade of mercury, its interim storage and final disposal, and develop strategies for contaminated sites.

The Minamata Convention will enable information and assistance exchange, public awareness, research, and monitoring. Parties of the Convention will be required to report on measures taken to implement certain provisions. The Convention will be periodically evaluated to assess its effectiveness at meeting its objective of protecting human health and the environment from mercury pollution (UN Environment, 2017a).

3.4.3 UNEP Global Mercury Partnership

In February 2005, the UNEP Governing Council established the Global Mercury Partnership, a voluntary multi-stakeholder partnership aimed at reducing use and emissions of mercury globally to protect human health and the environment from the releases of mercury and its compounds. The United States was a catalyst in the formation of the Partnership. The US EPA serves as lead for the Mercury Cell-Chlor-Alkali and Product Partnership Areas, and co-chairs the Partnership Advisory Group, which provides advice and guidance to the Global Mercury Partnership to encourage the work of the partnership areas.

The Partnership is divided into seven areas with the following leads or co-leads:

- Mercury Emissions from Coal – International Energy Agency Clean Coal Center
- Mercury Air Transport and Fate Research – Consiglio Nazionale delle Ricerche (CNR) Institute for Atmospheric Pollution, Italy and Biodiversity Research Institute (BRI)
- Mercury Waste Management – Government of Japan
- Mercury Cell Chlor-Alkali Production – Government of the United States (US EPA), United Nations Industrial Development Organization (UNIDO)
- Artisanal and Small-Scale Gold Mining – Natural Resources Defense Council (NRDC), United Nations Industrial Development Organization (UNIDO)
- Mercury Supply and Storage – Government of Spain, Government of Uruguay
- Mercury in Products – Government of the United States (US EPA).

Canada is a member of the Mercury Air Transport and Fate Research as well as the Mercury Emissions from Coal Partnerships.

3.4.4 Arctic Contaminants Action Plan and the Arctic Monitoring and Assessment Program under the Arctic Council

Arctic Contaminants Action Plan (ACAP) and Arctic Monitoring and Assessment Program (AMAP) are bodies of the Arctic Council, an intergovernmental forum whose members include Canada, Russia, Norway, Denmark, Iceland, the United States, Sweden, and Finland. US EPA co-chairs the Mercury Project Steering Group under ACAP. In 2011, this group published a list of nine recommendations for reducing mercury in the Arctic (AMAP, 2011).

3.4.5 The Commission for Environmental Cooperation

The Commission for Environmental Cooperation (CEC) is an international organization that supports cooperation among Canada, Mexico, and the United States to address issues of environmental concern in North America. The CEC's mission is to facilitate collaboration and public participation in conservation, protection, and enhancement of the North American environment, specifically in the context of increasing economic, trade, and social links among the three countries. Mercury is considered persistent, bioaccumulative, and toxic by the CEC. Thus, the CEC Council prepared a North American Regional Action Plan (NARAP) to determine the level of contamination in the environment and in humans, to follow the trends over time, and to support mercury monitoring needs. The NARAP was closed out in 2013 (CEC, 2015).

4 Gap Analysis

4.1 Gaps and Needs for Action

The largest contributions of mercury loadings to the Great Lakes basin are through electricity generation facilities within the United States, and from long-range transport. In each case, air monitoring is critical for assessing trend analysis, source attribution and predictive modeling. Mercury in Great Lakes air, precipitation, water, sediment, fish, and wildlife has been monitored to some degree since the 1960's; however, uniform long-term monitoring is lacking in areas of the Great Lakes basin. Data collected by federal, state, provincial, Tribal/First Nations/Métis, and other governmental agencies or programs need to be consistent and of uniform quality.

There is an overall lack of knowledge in how the changing climate may impact the mercury cycle. Climate can impact physical characteristics and functions of the ecosystem; this affects all processes in the biogeochemical cycle of mercury (ECCC, 2016b). Of concern is the rate of methylmercury formation within the environment, and its corresponding ecological risk. Additional topics that have been previously identified as mercury cycle knowledge gaps include (ECCC, 2016b):

- Limited information on the processes driving emission of mercury from various surfaces and water bodies;
- Lack of chemical identification of different species of atmospheric mercury and quantification of their deposition to surfaces;
- Lack of knowledge of the impact of acidity, temperature, and organic matter collectively on methylmercury production and bioaccumulation in freshwater aquatic systems;
- Insufficient information on methylmercury levels and production in the freshwater environment;
- Insufficient knowledge of factors promoting methylmercury in Great Lakes food webs and potential impacts of invasive species; and
- Lack of information on the fate and transport of mercury within terrestrial ecosystems.

There is also a gap in the ability of models to accurately predict the relationship between mercury emissions and fish concentrations due to the intrinsic complexity of atmospheric mercury chemistry and mercury methylation pathways and processes. Additional emissions data and monitoring data from both biotic and abiotic systems are needed to enhance the utility of models to effectively predict fish populations within specific areas that are at risk due to mercury exposure (ECCC, 2016b). Such models would be useful to provide a comprehensive evaluation of how well existing regulatory programs are working to limit and reduce mercury impacts to the Great Lakes, another current gap. Further development of innovative tools like isotopic mercury ratios will help with a weight-of-evidence approach to evaluation of sources to the Great Lakes.

Within the United States, the Mercury Export Ban Act of 2008 (MEBA is intended to reduce the availability of elemental (metallic) mercury in local and global markets. MEBA amends TSCA to prohibit the export of elemental mercury from the United States effective January 1, 2013. By reducing the supply of elemental mercury in commerce, MEBA seeks to reduce the use of mercury in artisanal mining and other commercial purposes globally. However, there has been some expressed concern that restrictions on the global supply of mercury, such as export bans or restrictions, may lead to higher prices for recycled mercury, which could, in turn, have the negative result of increasing primary mercury mining, likely in locations other than the country that originally put the ban or restriction in place (Bender and Narvaez, 2016). Primary mercury mining produces very significant releases of mercury to the environment and is an overall less environmentally sound method of meeting global mercury demand.

There have been a number of studies examining the relative health benefits of fish consumption compared with the risks of mercury exposure (Ginsberg and Toal, 2009; US FDA, 2014; Ginsberg, 2016; Raymond et al., 2017). There is, however, an ongoing need to assess the balance between the nutritional benefits of fish consumption and the risk of methylmercury exposure as additional information becomes available, particularly since the relationship between methylmercury exposure and other diseases/conditions is not fully understood or appreciated. In addition, there are challenges with addressing mercury contamination via an emphasis on fish consumption advisories, in particular for those communities that may have a heavy reliance on fishing and fish consumption (for reasons including sustenance, cultural, or both).

4.2 Exceedances of or Non-compliance with Environmental Quality Guidelines

While many environmental quality guidelines exist for mercury in Canada and the United States, not all environmental monitoring programs monitor mercury in different media (air, fish, water, sediment, birds, etc.) with the same frequency. From the available information, the offshore waters in the Great Lakes are below the water CEQG for the protection of aquatic life; however, this guideline does not address exposure through food or bioaccumulation to higher trophic levels and may not adequately protect all species (e.g. piscivorous fish). Sediment concentrations within some lakes (Lakes Erie and Ontario) regularly exceeded the sediment CEQGs (Table 7) (ITT, 2015).

In the U.S., exceedance of certain thresholds (e.g. of a water concentration-based water quality criterion or a fish tissue criterion) in a state's standards may lead to placement of waterbodies on a state's list of impaired waters in need of a total daily maximum load (TMDL) under Section 303(d) of the Clean Water Act, thus generally requiring the development TMDLs. Waters that do not meet the state's standards but have a TMDL and waters impaired by something other than a "pollutant" are not included in the 303(d) impaired waters list (US EPA, 2005).

The concentration of total mercury in whole Lake Trout from the Great Lakes has been shown to be below levels of concern for the health of fish consuming wildlife that were established in the 1987 GLWQA. However, mercury levels in fish are still sufficient to trigger fish consumption advisories in all five of the Great Lakes (**Figure 8**). Long-term mercury trends in walleye and largemouth bass fillets from the Great Lakes indicate decreasing concentrations, however, fish fillet concentrations still exceed US EPA mercury criteria for the protection of human heath (0.3 µg/g wet weight) and 2013 province of

Ontario recommendations (0.26 µg/g wet weight) for sport fish consumption by sensitive populations (Evers et al., 2011; Monson et al., 2011; OMOECC, 2013; ITT, 2015).

All eight Great Lakes states use the Protocol for Mercury-based Fish Consumption Advice (Mercury Addendum). The Mercury Addendum provides methods for determining consumption advice, but resulting advice may differ, reflecting regional differences in species occurrence, mercury concentrations and other factors (Great Lakes Consortium, 2007). Some of these differences can be found in Appendix D of the Mercury Protocol, A Survey of Great Lakes States Mercury Fish Advisory Methods.

5 Risk Mitigation and Management Options to Address Gaps

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

5.1 Regulations, and Other Risk Mitigation and Management

In accordance with the recently enacted Lautenberg Act amendments to TSCA, the US EPA is required to establish a mercury inventory for supply, use, and trade in the United States, and requires reporting by any person who manufactures mercury or mercury-added products or otherwise intentionally uses mercury in a manufacturing process. This information could be used to periodically update the mercury inventory, identify manufacturing processes or products that use mercury, and recommend actions to reduce mercury use. .

In 2017, Canada added mercury to the Export Control List and amended the associated Export of Substances on the Export Control List Regulations under CEPA. These amendments require exporters of mercury and products containing mercury to notify the Minister prior to export and set out the limited purposes for which export may occur (ECCC 2018). Comprehensive restrictions apply to exports of elemental mercury at concentrations of 95% or more by weight. Until recently, mercury exports were not controlled or prohibited, except as hazardous waste or hazardous recyclable material regulated under the *Export and Import of Hazardous Waste and Hazardous Recyclable Material Regulations*.

In 2010, the Great Lakes Regional Collaboration (GLRC), a binational task force, produced the Great Lakes Mercury Emission Reduction Strategy (GLRC, 2010). The strategy includes more than 34 recommended regulatory and voluntary actions to further control mercury pollution, including the following:

- *Require best available control technology for new and modified sources.* The GLRC strategy recommended that all states require Best Available Control Technology for new and modified sources if they annually emit 10 pounds of mercury (or less, at the state’s discretion).

Summary of Regulations and Other Risk Management Strategy Options

- Evaluate the effectiveness of existing regulatory programs to ensure maximum efficiency and overall positive implications on a global scale (Canada)
- Review and update actions to match current scientific understanding and regional context (Canada)
- Identify any manufacturing processes or products that intentionally add mercury (US)
- Continue to reduce mercury emissions resulting from coal-fired generation of electricity (Canada)
- Continue implementation of domestic regulations and other risk management activities for mercury (Canada and US)
- Implement the National Strategy for Safe and Environmentally Sound Disposal of Lamps Containing Mercury (Canada)
- Continue remediation of mercury-contaminated sites and sediments (Canada and US)
- Amend the *Products Containing Mercury Regulations* to further reduce mercury in products (Canada)

5.2 Compliance Promotion and Enforcement

While there are many regulations in effect for mercury and mercury emissions, these regulations need to be effectively communicated to the appropriate entities and enforced. These regulations were discussed in Section 3.

Internationally, both the United States and Canada are Parties to the Minamata Convention. Canada and the United States continue to support international initiatives to reduce mercury emissions and prevent release of mercury into the environment. Implementation of the Minamata Convention is essential and guidance adopted at COP1 and COP2, held in November of 2018, and at COP3, held in November 2019, will help address the next phase of global implementation.

Summary of Compliance Promotion and Enforcement Strategy Options

- Continue to ensure compliance with domestic and international mercury activities and initiatives (Canada and US)
- Continue implementation of respective obligations of the Minamata Convention on Mercury (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 mercury release or exposure. User-friendly materials targeting specific public audiences may be appropriate to aid in preventing mercury pollution from being incorporated into general solid waste streams and providing awareness regarding potential mercury sources of health hazards. Outreach/education is also needed to ensure affected populations have an awareness and understanding of existing fish consumption advisories. Key elements of outreach and education include:

providing knowledge of where to obtain the most timely and relevant information; and how to apply advisories to individuals (e.g., young children, pregnant women) and communities that may have a heavy reliance on fishing and fish consumption.

US EPA's TRI database can be used to track progress in reducing waste generation. The TRI database should be maintained and leveraged to maximize P2 activities being conducted by industries in the Great Lakes basin. 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 mercury in the environment. Waste reduction success stories may be noted in region-specific journals, websites, and/or at conferences.

Canada's NPRI database tracks mercury emissions. Industries can see their emissions and releases decreasing over time as they implement P2 activities.

In Ontario, the Toxics Reduction Act, which became law on June 5, 2009, is intended to reduce the use and creation of toxic substances, including mercury, by regulated facilities. While implementation of the plan is not mandatory, a facility may realize economic, environmental, and social benefits through toxic substance reductions.

Summary of Pollution Prevention Strategy Options

- Enhance public outreach and educate the public and facility staff on potential sources of mercury and proper actions to follow when handling mercury containing products (Canada and US)
- Enhance public outreach and education on site-specific fish consumption advisories (Canada and US)
- Encourage industries to track their P2 activities and efforts in the National Pollutant Release Inventory (NPRI) or Toxics Release Inventory (TRI), or via P2 promotion activities (fact sheets, case studies) (Canada and US)
- Highlight pollution prevention successes (Canada and US)
- Implement best available techniques and best environmental practices for new and substantially modified sources (Canada)

5.4 Monitoring, Surveillance, and Other Research Efforts

Numerous monitoring, surveillance, and remediation activities have been conducted since the 1970s. However, due to the complexity of mercury and methylmercury interactions in the environment, a clear understanding of the long-term interactions is lacking. Domestically, both Canada and the United States should continue to assess and, where appropriate, remediate mercury-contaminated sites and sediments related to historical sources and evaluate the effectiveness of remediation activities.

Additional research is needed to fill knowledge gaps with respect to methylation dynamics and the differential impacts of mercury in nearshore versus offshore environments. Monitoring data, particularly for air, is needed for inclusion in models to track long-range atmospheric transport, the rate of methylmercury formation in the environment, and the implications of climate differences for the overall mercury cycle. These data will also help assess the effectiveness of the implemented regulations. The rate of methylmercury formation corresponds to ecological risks and risk associated with human consumption of Great Lakes fish populations. Therefore, a clear understanding is imperative. Canada has developed a passive air sampler for gaseous mercury monitoring in ambient air and is in the process of testing the sampler to determine how it compares to traditional air monitors and implementing it in various geographic locations. Such a sampler could also be of value for monitoring in the Great Lakes.

The development of a cost-effective and useful means of collecting mercury concentrations from a variety of sources as part of a comprehensive mercury monitoring network (e.g. MercNet) is essential. Implementation of a passive sampler capable of monitoring total mercury levels in air and development of passive samplers for monitoring speciated mercury compounds could be used in conjunction with active sampling to better understand the spatial distribution and behavior of mercury in the Great Lakes and the region as a whole (Huang et al. 2014, McLagan et al. 2016). Source tracking for areas of localized mercury contamination may be a need in the future. Efforts such as Project Trackdown, which uses a multimedia weight-of-evidence approach for tracing sources of polychlorinated biphenyls (PCBs) in the Great Lakes, may be a model system for future mercury studies (Benoit et al., 2016).

Reports on the current state of mercury contamination and the ecological and human health risks that mercury poses 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 the Great Lakes basin.

While the ultimate success of the strategy depends on the efforts of the Great Lakes community, it is suggested that the strategy and its implementation progress should be reviewed on a regular basis and reported through the Progress Report of the Parties.

Summary of Monitoring, Surveillance, and Other Research Strategy Options

- Continue monitoring mercury in environmental media in the Great Lakes (air, precipitation, sediment, fish, and other wildlife) and publish results in a variety of publications (e.g., online and open data portals, government reports and scientific journals) to maximize the intended audience (Canada and US)
- Continue efforts to update and maintain domestic mercury emissions inventories in a manner such that regional and global emissions can be tabulated (Canada and US)
- Conduct additional research on methylation dynamics and the differential impacts of mercury in nearshore versus offshore environments (Canada and US)
- Utilize and as feasible, enhance existing models to track long-range atmospheric transport and the rate of methylmercury formation in the environment and its corresponding ecological risk (Canada and US)
- Develop cost-effective, reliable and effective tools (e.g., passive samplers) for collecting long-term mercury multi-media monitoring data (Canada and US)
- Develop and populate a structured data system to track mercury sources, manifests, waste, and products (Canada)

5.5 Domestic Water Quality

Domestic waters include all water used for indoor and outdoor household purposes. There is a need for reviewing existing standards to ensure that they are based on the latest science, to assist states and Ontario (and other Canadian provinces and territories) in identifying areas where standards are exceeded. Compliance with the ambient water quality guidelines of both countries will ensure drinking water is protected since the ambient criteria are well below the drinking water standards.

Summary of Domestic Water Quality Strategy Options

- Review and update existing domestic water quality guidelines and standards, if necessary (Canada and US)

6 Conclusions

Under Annex 3 of the GLWQA, mercury has been identified as a CMC that originates from anthropogenic sources. The documented impacts of mercury exposure of fish and wildlife in the Great Lakes basin are significant (Evers et al., 2011). Elevated mercury levels have been detected in Great Lakes biota (e.g., birds, fish, mammals), at all levels of the food web (e.g., plankton, fish, loons), and across many different habitat types (e.g., lakes, wetlands, streams, forests) throughout the region. Much of the point-source mercury pollution has been controlled, allowing partial recovery of the Great Lakes, as shown by lower mercury concentrations in lake sediments in the lower Great Lakes (e.g., Lake Ontario) and in declines in fish mercury since the years of peak pollution.

There have been significant international, national (United States and Canada), and regional efforts to reduce mercury emissions to the environment since the 1980s. Binational efforts have made significant strides in regulating industrial mercury emissions and in cleaning historic mercury-contaminated sites (US EPA, 2016a). However, mercury is still detected at elevated concentrations in soils, sediment, water, air, biota tissues, and wastes throughout the Great Lakes basin, such that fish consumption advisories due to mercury concentrations are in effect in all five Great Lakes (**Table 7**). Although there are some emitting sectors, this is primarily attributable to legacy accumulations from historical emissions and discharges in the U.S. and Canada, as well as long-range atmospheric transport.

Under the GLWQA, ECCC and the US EPA have a mutual goal for virtual elimination of mercury emissions originating from human activities in the Great Lakes basin. This goal will be achieved through a variety of programs and actions with a primary emphasis on pollution prevention. Binational cooperation is needed to coordinate monitoring and surveillance efforts, maximize research initiatives, and cost-effectively monitor and track mercury 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 ways and/or improving upon existing ways to mitigate and manage mercury risks will improve the health of the ecosystem and residents of the Great Lakes basin and will preserve the quality of the Great Lakes for future generations.

7 Figures

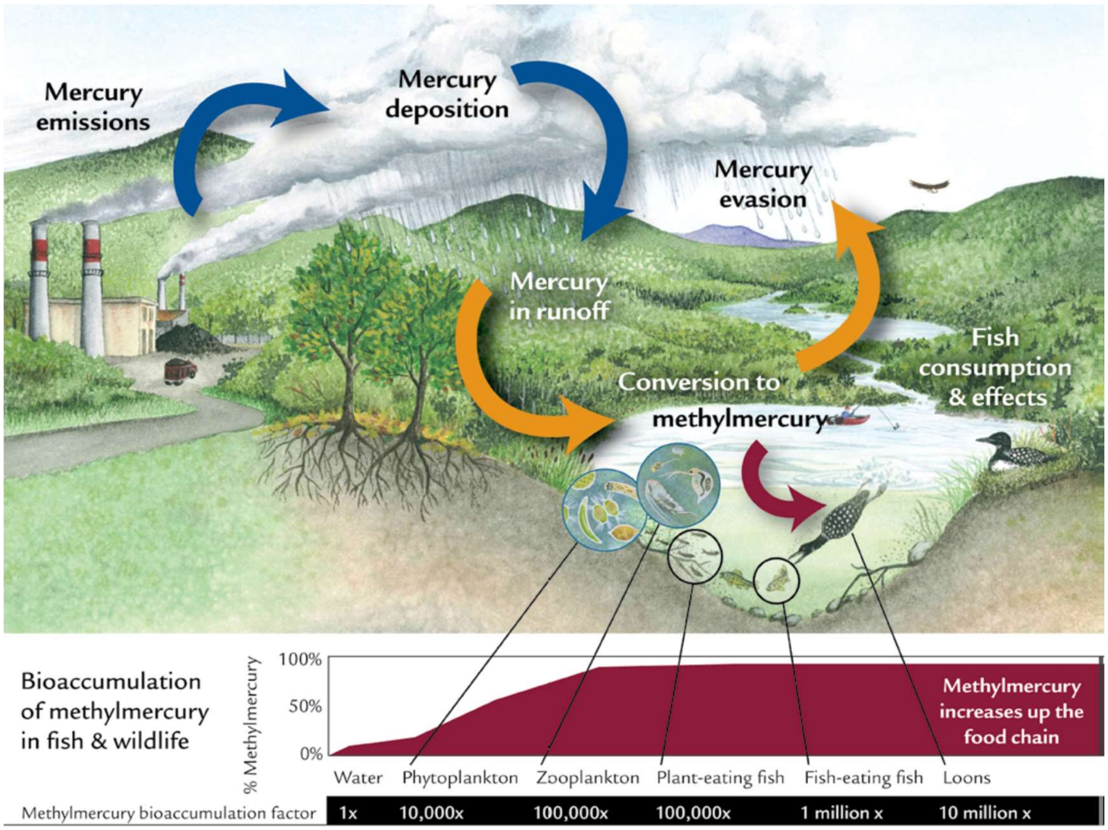

Figure 1. *The Mercury Cycle. Source: Evers et al. (2011)*

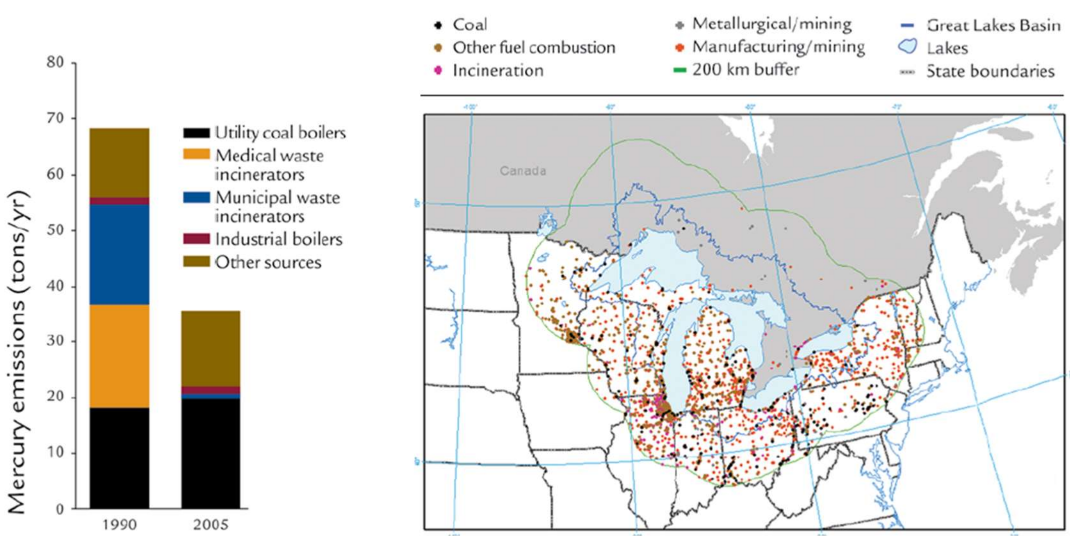

Figure 2. *Decline in Mercury Emissions 1990-2005. Source: Evers et al. (2011)*

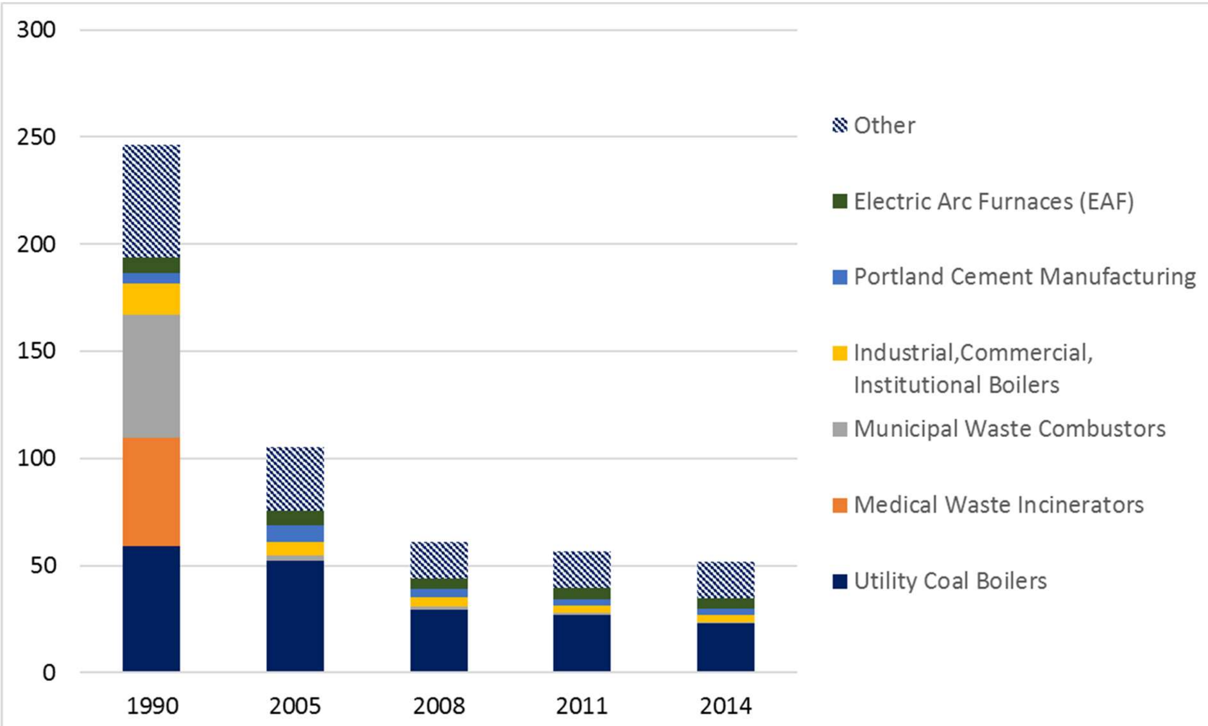

Figure 3. *Trends in National Emissions Inventory (NEI) Mercury emissions (tons) Source: United States EPA 2014 NEI version 2 Technical Support Document (TSD)*

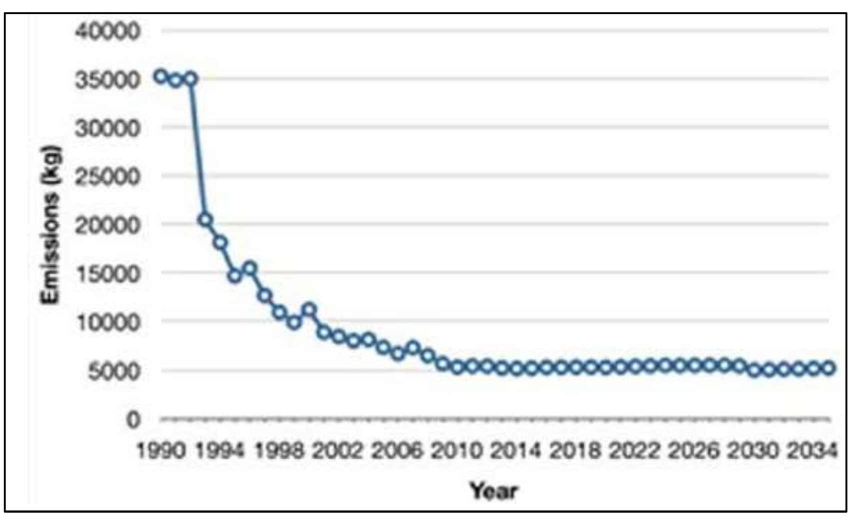

Figure 4*. Historical and Projected Canadian Mercury Air Emissions Trends. Source: ECCC (2016b)*

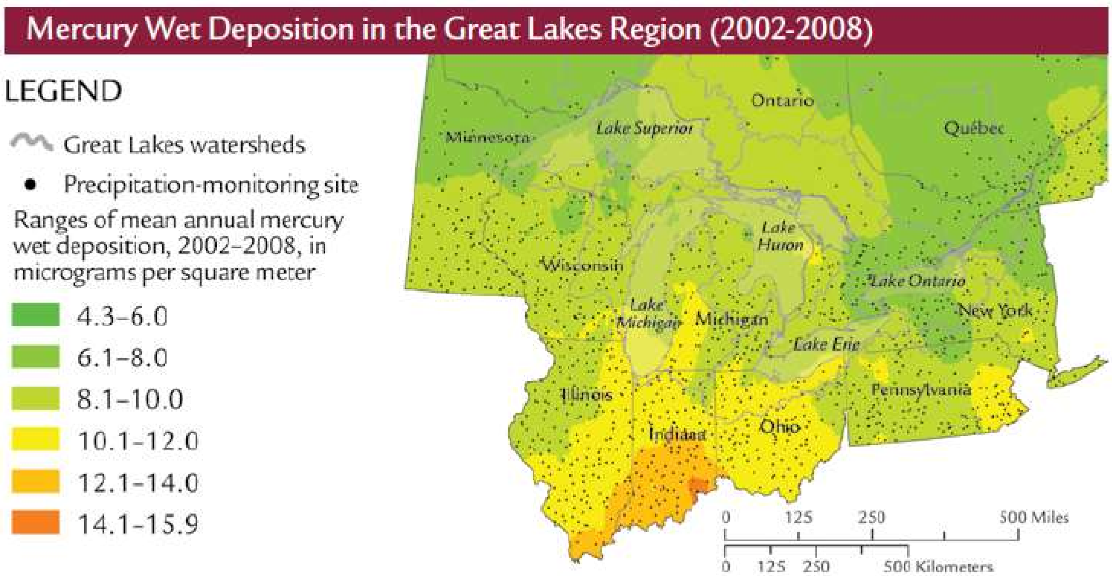

Figure 5. *Seven-year mean annual mercury wet deposition based on NADP/MDN monitoring data. Source: Evers et al. (2011)*

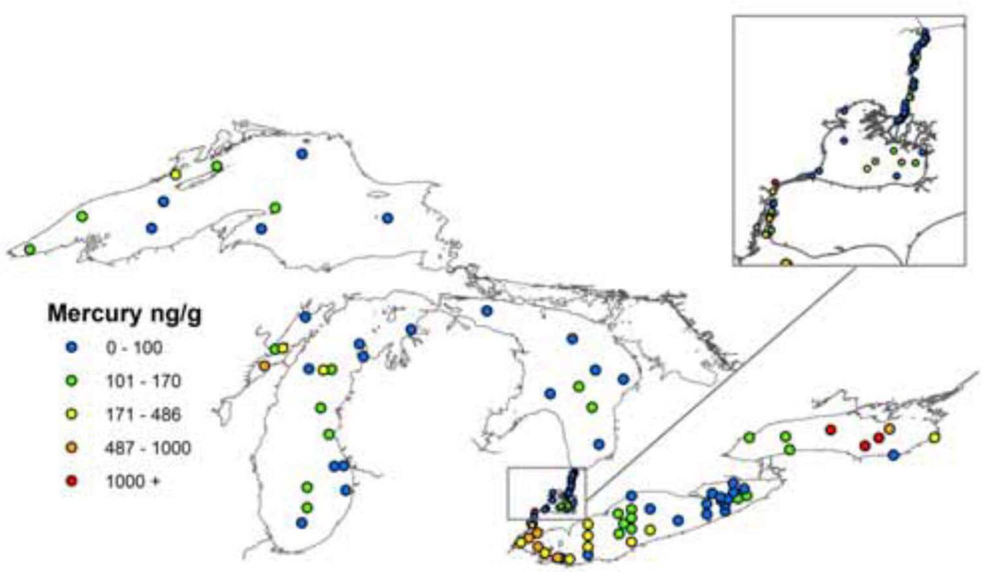

Figure 6*. Spatial Distribution of Mercury in Great Lakes Sediments. Inset is Lake St. Clair Corridor. Source: State of the Great Lakes Technical Report 2017*

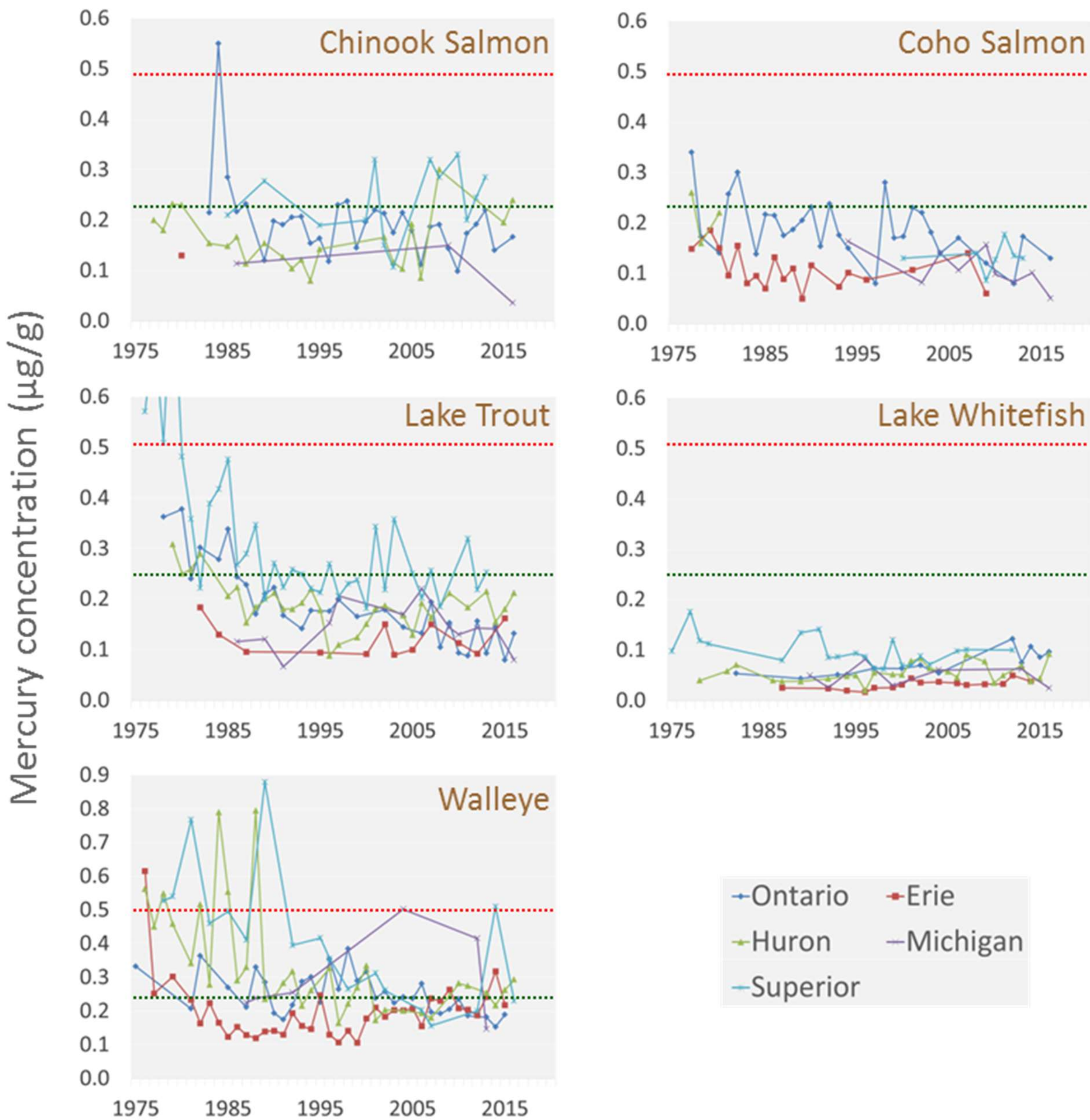

Figure 7. Long-Term Mercury Trends in Chinook Salmon, Coho Salmon, Lake Trout, Lake Whitefish and Walleye in the Great Lakes. Source: State of the Great Lakes Technical Report 2019.

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Figure 8. *Great Lakes Fish Consumption Advisories for Mercury.*
Source: Evers et al. (2011), updated from US EPA (2011)

8 Tables

***Table 1.** Physical and Chemical Properties of Mercury and Select Compounds.*

Property	Mercury	Mercuric Chloride	Mercuric Oxide	Mercury Sulfide	Methylmercury Chloride	Dimethyl Mercury
Chemical Symbol	Hg	$HgCl_2$	HgO	HgS	CH_3HgCl	$(CH_3)_2$ Hg
Physical State	Liquid	Crystalline solid	Crystalline powder or scales	Solid	NA	Liquid
Molecular Weight (g/mol)	200.59	271.49	216.59	232.65	248.69	230.66
Color	Shiny, silvery-white	White	Red, Orange-red, orange-yellow	Red or black	NA	Colorless
Crystal Structure	Rhombohedral	Rombic or Orthorombic	Orthorombic	NA	NA	None
Density, g/cm^3	13.5					
Melting Point, °C	-39	277	Decomposition @ +500	Sublimation 584	Sublimation 167	NA -S
Boiling Point, °C	357 @ I atm.	303 @ I atm.	NA S	NA S	NA S	96 @ I atm.
Vapor Pressure (Pa)	0.180 @ 20°C	8.99×10^{-3} @ 20°C	9.20×10^{-12} @ 25°C	NA S	1.76×10^{-12} @ 25°C	8.3×10^{3} @ 25°C
Water Solubility (g/L)	49.4×10^{-6} @ 20°C	66 @ 20°C	5.3×10^{-2} @ 25°C	~ 2×10^{-24} @ 25°C	~ 5 to 6 @ 25°	2.95 @ 24
Henry's Law Constant (Pa m^3 mol^{-1})	729 @ 20°C 0.32 @ 25°C 0.18 @ 5°C	3.69×10^{-5} @ 20°C	3.76×10^{-11} @ 25	NA S	1.6×10^{-5} @ 25°C and pH = 5.2	646 @ 25°C 0.31 @ 15°C 0.15 @ 0°C
Octanol-Water Partition Coefficient (dimensionless)	4.2	0.5	NA S	NA S	2.5	180

Sources: Schroeder and Munthe (1998); Kim et al. (2016),
~ - approximately; atm. – atmosphere; NA – not available

__Table 2.__ Estimated Amount of Elemental Mercury in Mercury-Added Products in the United States (2013)

PRODUCTS/COMPONENTS	TOTAL MERCURY SOLD IN THE UNITED STATES (METRIC TONS)			
	2001	2004	2007	2013
Switches and Relays	52.44	46.97	27.91	17.7 (2010)
Dental Amalgam	27.91	27.57	14.95	14.5
Thermostats	13.27	12.85	3.50	not reported
Lamps	9.22	8.67	9.64	4.7
Miscellaneous	4.64	2.18	2.52	2.5
Batteries	2.68	2.30	1.88	<0.1
Other products*	5.46	4.35	2.32	0.6
Total (approximate)	**115.6**	**104.51**	**62.78**	**40.1**

*Chemicals, sphygmomanometers, thermometers, manometers, and barometers

Source: Carpenter et al. (2011 IMERC, US EPA 2017c)

__Table 3__. Sources of Global Mercury Supply, 2015.

Mercury Supply Sector	Range (metric tons)
Dedicated mercury mining	1630–2150
By-product mercury from non-ferrous metal sector	440–775
Recycled/re-use mercury from chlor-alkali facilities	370–450
Recycled mercury—others	1040–1410
Commercially available mercury stocks	As needed (+)
Range of Total	3480–4785+

Source: United Nationals Environment Program(2017c)

__Table 4__. Total Mercury Emissions in Canada by Sector, 1990-2015.

Sector	Total Emissions per Year (tons)					
	1990	**1995**	**2000**	**2005**	**2010**	**2015**
Non-ferrous Metal Mining and Smelting	24.9	4.7	1.9	1.7	0.5	0.2
Electric Power Generation	2.3	2.0	4.0	2.1	1.6	0.7
Cement and Concrete industry	0.5	0.4	0.4	0.2	0.3	0.3
Iron and Steel Industries	0.9	1.0	1.0	0.7	0.4	0.7
Waste Sectors	3.8	4.3	2.1	1.4	1.3	0.7
Other	2.9	2.4	1.7	1.2	1.2	1.8
Total Emissions	35.3	14.7	11.2	7.3	5.3	4.4
% per year decrease since 1990		58.4	68.3	79.3	85.0	87.5

Source: ECCC (2016b)

Table 5. United States Federal Statutes that Apply to Mercury.

Regulation	Summary of Elements
Frank R. Lautenberg Chemical Safety for the 21st Century Act on June 22, 2016	Amended TSCA to include additional objectives in the Act specific to mercury and mercury compounds (https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/frank-r-lautenberg-chemical-safety-21st-century-act-5)
Mercury Export Ban Act (MEBA) of 2008	This law focuses on reducing the availability of elemental (metallic) mercury from local and global markets through a reduction in supply. (https://www.congress.gov/110/plaws/publ414/PLAW-110publ414.pdf)
Mercury-Containing and Rechargeable Battery Management Act of 1996	This law phases out the use of mercury in batteries and provides for cost-effective means to dispose of regulated batteries, including used nickel cadmium (Ni-Cd) batteries and small sealed lead-acid (SSLA) batteries. (https://www.epa.gov/sites/production/files/2016-03/documents/p1104.pdf)
Toxic Substances Control Act (TSCA) §6(f) – 15 U.S.C. 2605(f)	Title 1 of TSCA prohibits the sale, distribution, or transfer of elemental mercury by Federal agencies, state or local agencies, or any private individual or entity except for the purposes of storage. (https://www.epa.gov/enforcement/toxic-substances-control-act-tsca-and-federal-facilities)
Clean Air Act (CAA) 42 U.S.C. § 7401 et seq. (1970) Section 112 and Section 129	Section 112 authorizes US EPA to regulate hazardous air pollutant emissions, including mercury, from new and existing stationary sources. Section 129 provides authority to address emissions of pollutants, including mercury, from new and existing solid waste combustion units. (https://www.epa.gov/laws-regulations/summary-clean-air-act)
Clean Water Act (CWA) 33 U.S.C. § 1251 et seq. (1972)	Establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. Authorized the National Pollutant Discharge Elimination System (NPDES), wastewater standards for industry, and water quality standards for contaminants within surface waters. (https://www.epa.gov/laws-regulations/summary-clean-water-act)
Emergency Planning and Community Right-to-Know Act (EPCRA) Section 313	Requires industrial and federal facilities to report mercury emissions through the Toxics Release Inventory (TRI) Program. (https://www.epa.gov/sites/production/files/documents/2001hg.pdf)
Resource Conservation and Recovery Act (RCRA) 40 CFR Parts 262 - 265	Mercury wastes are manifested using the RCRA Uniform Hazardous Waste Manifest. Individual states are largely responsible for implementing the RCRA program and therefore, some states may have stricter requirements. (https://www.epa.gov/laws-regulations/summary-resource-conservation-and-recovery-act)
Safe Drinking Water Act (SDWA) 42 U.S.C. § 300f et seq. (1974)	Authorizes US EPA to establish minimum standards to protect all waters actually or potentially designed for drinking use. Requires all owners or operators of public water systems to comply with primary (health-related) standards. Mercury maximum contaminant level goal (MCLG): 2 ppb; maximum contaminant level (MCL): 2 ppb. Individual states have the primary responsibility for enforcing drinking water standards. (https://www.epa.gov/laws-regulations/summary-safe-drinking-water-act)

Table 5. (continued) *United States Federal Statutes that Apply to Mercury.*

Regulation	Summary of Elements
Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) or "Superfund" 42 U.S.C. § 9601 et seq. (1980)	Gives the Federal government authority to respond to mercury emergencies and clean up uncontrolled or abandoned hazardous waste sites (US EPA, 2015c). (https://www.epa.gov/laws-regulations/summary-comprehensive-environmental-response-compensation-and-liability-act)
Effluent Limitation Guidelines and Standards for the Dental Category 40 CFR 441	This rule requires dental offices to use amalgam separators and two best management practices recommended by the American Dental Association (ADA). This rule went into effect on July 14, 2017 for all new dental facilities, while pre-existing sources must comply by July 2020 (US EPA, 2017a). (https://www.federalregister.gov/documents/2017/06/14/2017-12338/effluent-limitations-guidelines-and-standards-for-the-dental-category)
Source: US EPA (2017b)	

Table 6. *Summary of Great Lakes States Mercury Programs from a 2011 Survey.*

State	Overall Mercury Action Plan	Inventory Mercury Air Emissions Sources	Mercury Monitoring – Stack Testing	Mercury Monitoring – Air Deposition	Mercury Monitoring –Fish Consumption Advisory	Programs to Manage Mercury – Containing Products	Mercury Dental Programs	State Requirements for Mercury Switch Recovery	Participant in National Vehicle Mercury Switch Recovery	Statewide TMDL	Multistate TMDL
Illinois			X	X	X	X	X	X	X		
Indiana	X	X	X	X	X	X	X	X	X		
Michigan	X	X	X	X	X	X	X		X	Draft	
Minnesota	X	X	X		X	X	X		X	X	
New York	X	X	X	X	X	X	X		X		X
Ohio		None	X	X	X	X	X		X		
Pennsylvania*				X	X	X			X	X	
Wisconsin		X		X	X	X	X		X		

Source: Quicksilver Caucus (2012)

* Pennsylvania information was gleaned from the Pennsylvania Department of Environmental Protection (www.dep.pa.gov).

***Table 7**. United States Standards and Canadian Environmental Quality Guidelines for Mercury and Methylmercury and Average Great Lakes Concentrations.*

Medium/Guideline	United States Standards	Canadian Environmental Quality Guideline	Average Great Lakes Concentration	Comment/Source
		Mercury		
Drinking Water Water Quality Criteria for the Protection of Human Health	2.0 µg /L 1.8 ng/L	1.0 µg/L		US MCL per the Safe Drinking Water Act (ITT, 2015); Health Canada (1986); 40 CFR 132 (US EPA, 1997)
Water Quality Guidelines for the Protection of Aquatic Life	1.3 ng/L	26 ng/L	0.24-0.54 ng/L	CCME (1999 and updates); ITT (2015); US EPA (1997)
Sediment Quality Guidelines for the Protection of Aquatic Life		486 µg/kg dw PEL 170 µg/kg dw TEL	50-586 µg/kg dw	CCME (1999 and updates); ITT (2015)
Soil Quality Guidelines for the Protection of Environmental and Human Health Agricultural, Residential and Parkland Land Uses Commercial Land Use Industrial Land Use		 6600 µg/kg dw 24000 µg/kg dw 50000 µg/kg dw		CCME (1999 and updates)
Air	0.3 µg/m³ *			US EPA (1995)
Whole Body Lake Trout for the Protection of Aquatic Life	500 ng/g		121-233 ng/g	1987 GLWQA (IJC, 1987); McGoldrick and Murphy (2016)
Fish Fillet Human Health Criterion	0.3 µg/g ww	0.5 µg/g ww		(Evers et al., 2011); ITT (2015)
Blood: sensitive populations	5.8 µg/L	8 µg/L		ITT (2015)
		Methylmercury		
Water Quality Guidelines for the Protection of Aquatic Life (freshwater)	1.4 µg/L CMC 0.77 µg/L CCC	0.004 µg/L		*US EPA (1996); CCME (1999 and updates)*
Tissue Residue Quality Guideline for the Protection of Wildlife Consumers of Aquatic Biota		33 µg/kg diet ww		CCME (1999 and updates)
US FDA Action Level	1 mg/kg			*ITT (2015)*

CCC = Criterion Continuous Concentration (chronic); CMC = Criterion Maximum Concentration (acute); dw = dry weight; MCL = Maximum Containment Level; PEL = Probable Effects Level; TEL = Threshold Effects Level; ww = wet weight

* this value is an inhalation reference concentration, not a standard, and has no regulatory standing. It is an estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a G-6 lifetime. It can be derived from a NOAEL, LOAEL, or benchmark concentration, with uncertainty factors generally applied to reflect limitations of the data used. Generally used in EPA's non-cancer health assessments. (https://cfpub.epa.gov/ncea/iris/iris_documents/documents/subst/0370_summary.pdf)

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