

Mercury in the Great Lakes Basin: Background Paper Final Report

**Prepared for the Commission for Environmental Cooperation
April 2004**

Prepared by
Leah Hagreen
and
Leslie Kulperger

Mercury Recovery Fund
1216 Yonge Street, Suite 201
Toronto, ON M4T 1W1

lhagreen@fes.uwaterloo.ca

ACKNOWLEDGEMENTS

The authors would like to thank the Commission for Environmental Cooperation and staff, and particularly the Mercury Task Force, for the opportunity to undertake this research. Thank you as well to Mark Cohen (National Oceanographic and Atmospheric Agency), Leonard Levin (Electric Power Research Institute) and William Walsh (American Dental Association) for their comments on this paper. Thanks go out to those individuals and organizations, of which there are too many to name, whose previous research made this report possible. The findings in the report are the sole responsibility and opinion of the authors.

TABLE OF CONTENTS

EXECUTIVE SUMMARY	1
1 INTRODUCTION	2
2 GLOBAL MERCURY CYCLING.....	2
3 MERCURY CYCLING: EASTERN NORTH AMERICA TO THE GREAT LAKES	2
4 GLOBAL MERCURY.....	3
4.1 Global Mercury Production, Use, and Flow	6
4.2 Mercury Trade Value.....	9
5 MERCURY POLICY	10
6 MERCURY IN THE GREAT LAKES BASIN.....	12
7 IMPACTS OF MERCURY IN THE GREAT LAKES BASIN.....	13
7.1 Human Health Impacts and Costs.....	14
7.2 Impacts of Mercury on the Great Lakes Environment.....	17
7.3 Effect of Reducing Mercury Contamination.....	18
8 ECONOMIC CONSEQUENCES OF MERCURY TO GREAT LAKES	19
9 CONCLUSIONS.....	20

EXECUTIVE SUMMARY

Mercury is a toxic element whose unique properties make it one of the most useful and pervasive substances, and as such, concentrations in places around the world have risen to levels of concern. The Great Lakes is one such place. There have been intensive efforts by many government and international bodies to reduce the use and emission of mercury to the environment. The lack of regulations in developing nations means that mercury releases continue unabated in many countries. Deliberate use of the toxin continues, perhaps being driven by its low market price and lack of knowledge about the environmental and human health consequences of its toxic properties, as countries struggle to address disposal and recycling issues. One of the largest industrial emitters in the world is coal-fired electricity generation, a sector that continues to grow, and remains unrestricted in many countries.

Mercury's capacity for long-range atmospheric transport demonstrates a need for global scale reductions efforts. Although Canada, the United States and Western Europe have reduced the use and emission of mercury, their boundaries are subject to mercury flowing from external regions. Conversely, mercury regulations in developed nations reduce market value by decreasing demand. A low market value will increase mercury's appeal, particularly in unregulated regions, thereby increasing its use and potential emission. Mercury's unique properties, widespread applicability, and low market value require a concerted global effort to restrict its emissions to the environment.

Mercury releases in the Great Lakes basin have been cut by more than 11 tonnes since 1988. Declining emissions both inside and outside the basin has resulted in reduced mercury levels in study areas across the Great Lakes region. Despite these achievements, mercury's presence in Great Lakes eco-region continues, partly due to continued deposition to the region from sources outside the basin. This has caused broad scale impacts to wildlife, fisheries, and even human health. Though little study has been done on the impact of mercury on human health in the Great Lakes region, alarmingly up to one in 12 women in the United States have mercury levels in their bodies which exceed US EPA health guidelines, putting their future children at risk. Fish consumption advisories may not be adequately protecting people's health, as they are outdated, and as many fisherfolk are unaware or do not follow these guidelines. The presence of fish consumption advisories in the Great Lakes basin has caused concern regarding the economic impacts on the fisheries industry. Where documented, the costs associated with these effects are significant. There remains however gaps in our knowledge concerning the effect of elevated levels of mercury in the Great Lakes basin. Through continued and increased diligence on both sides of the border – combined with some important efforts on the international stage – mercury deposition to the Great Lakes region can decline to the point where fish are safe to eat for every man, woman, child and loon in the basin.

1 INTRODUCTION

Mercury is a toxic substance that, through human and natural activities, cycles through the atmosphere, hydrosphere, and ecosphere where it can affect the health of both humans and wildlife. It enters the environment naturally through erosion, fire, and volcanic processes, and it is also released both directly from and as a bi-product of human industrial practices. Human activities, such as combustion, smelting, and mining, have elevated global mercury levels to approximately three times those found before industrialization.¹ The World Health Organization recently associated mercury poisoning with inhibiting the neuro-development of millions of children worldwide.² Numerous policies have been developed, principally in developed countries, to curb mercury emissions to the environment as a result of growing scientific evidence of mercury's toxic properties. These policies have resulted in lowered rates of emission and reduced human exposure in many regions of the world, including the Great Lakes basin. There remains however a need for a comprehensive global inventory of mercury releases so that governments can make more-informed policy decisions.³ This paper provides an overview of global mercury releases to air water and land in North America focusing on processes that deposit mercury into the Great Lakes, and examines the effects of mercury trade.

2 GLOBAL MERCURY CYCLING

Earth's physical influences, such as trade winds, temperature, humidity, solar radiation, and ocean currents can greatly affect the environmental transport and fate of emitted mercury. The chemical and physical form and the source characteristics of mercury also influence this fate and transport. In addition to earth systems, transport and deposition of anthropogenic mercury varies depending on source characteristics such as the media to which it is released (i.e. water, air, or land). Anthropogenic emissions contribute to background mercury concentrations and can be significant contributors to the total mercury burden in many locations. Oceans are significant and active mercury sinks whose currents are important pathways for long-range mercury transport.⁴ A large portion of human-related mercury emissions are gaseous elemental mercury which can travel long distances in the air, and can remain airborne for months or even up to one year.⁵ Global scale distribution of mercury is made possible as a result.

3 MERCURY CYCLING: EASTERN NORTH AMERICA TO THE GREAT LAKES

Atmospheric mercury emissions are thought to be predominantly in three forms: elemental mercury, divalent mercury, and particulate mercury.⁶ Though the overwhelming majority of airborne mercury is elemental, divalent and particulate mercury are more readily deposited and can have more significant impacts near emission sources. Divalent and particulate mercury fall out of the atmosphere in precipitation or as dry deposition (deposition of particulate and vapor-phase mercury in the absence of precipitation) as opposed to elemental mercury which can cycle in the atmosphere for months or years. There are complex processes in the atmosphere that interconvert mercury among its various forms, and this makes the overall behaviour of mercury difficult to predict. Anthropogenic mercury emission modeling for Eastern North America concluded that around 500 tonnes of mercury were emitted annually in the region, 81% of which was elemental mercury.⁷

To quantify mercury emissions in the Great Lakes basin, it is important to consider wind patterns and the mercury that they carry. Prevailing winds in North America are primarily from west to east with overlain seasonal patterns that derive mainly from the Gulf of Mexico circulating around a midlatitude high pressure system in the summer months, and the western Arctic in the winter months, following latitudinal waves in the jet stream (See Figure 1). For this reason, a considerable portion of the mercury deposited in the Great Lakes basin is from sources south and west of the Great Lakes. Atmospheric emissions of mercury from within the basin may be deposited locally, be carried further east (i.e. New York, Maritime provinces), or enter the global pool.



Figure 1: Prevailing Wind Patterns in US and Canada⁸

4 GLOBAL MERCURY

Available global mercury release data are incomplete, with gaps from both sources and countries that make it difficult to quantify the actual amount of mercury emitted annually into the environment. Existing global inventories of mercury released to the environment are based on a combination of reported and approximate data, and vary depending on several factors, such as reporting structures where required, and assumptions and interpretations where reporting is not obligatory. The need for a standard reporting structure to inventory mercury releases accurately was made evident in both Canada and the United States in 2000, when both nations reduced their pollutant reporting threshold for mercury significantly. The US Toxics Release Inventory (TRI) lowered its reporting threshold for mercury from annual releases of 4500 kilograms in 1999 to 5 kilograms in 2000.⁹ Mercury releases reported to the National Pollutant Release Inventory (NPRI) in Canada increased by over thirteen tonnes¹⁰ in 2000 as a result of an even more aggressive

decrease in the requisite annual reporting threshold – from 10 tonnes in 1999 to 5 kilograms in 2000.¹¹

Care must be taken when examining trend data from these reporting inventories. The apparent increase in mercury emissions in 2000 reflect the increase in reporting by many small, but cumulatively significant, sources of mercury. In actuality, releases in both Canada and the US have been on the decline since 1990.¹² Comprehensive reporting actions such as those established in Canada and the US offer a better understanding of the amount of mercury released to the environment from anthropogenic sources, but significant uncertainties in the emissions inventories still remain. The lack of information is even more apparent in many other countries, making estimates of global emissions challenging.

Table 1. Estimates of global atmospheric releases of mercury from a number of major anthropogenic sources in 1995 (metric tonnes per year). Adapted from UNEP, 2002.*¹

Continent	Stationary combustion	Non-ferrous metal production *5	Pig iron and steel production	Cement production	Waste disposal *2	Artisanal gold mining *4	Sum, quantified sources *3
Europe	186	15	10	26	12		250
Africa	197	7.9	0.5	5.2			210
Asia	860	87	12	82	33		1070
North America	105	25	4.6	13	66		210
South America	27	25	1.4	5.5			60
Australia and Oceania	100	4.4	0.3	0.8	0.1		100
Sum, quantified sources, 1995 *3,4	1470	170	30	130	110	300	1900 +300
Based on references:	Pirrone <i>et al.</i> (2001)	Pirrone <i>et al.</i> (2001)	Pirrone <i>et al.</i> (2001)	Pirrone <i>et al.</i> (2001)	Pirrone <i>et al.</i> (2001)	Lacerda (1997)	

- 1 Note that releases to aquatic and terrestrial environments - as well as atmospheric releases from a number of other sources - are not included in the table, because no recent global estimates have been made.
- 2 Considered underestimated by authors of the inventory.
- 3 Represents total of the sources mentioned in this table, not all known sources. Sums are rounded and may therefore not sum up precisely
- 4 Estimated emissions from artisanal gold mining refer to late 1980's/early 1990's situation. A newer reference (MMSD, 2002) indicates that mercury consumption for artisanal gold mining - and thereby most likely also mercury releases – may be even higher than presented here.
- 5 Production of non-ferrous metals releasing mercury, including mercury, zinc, gold, lead, copper, nickel.

Based on the information in Table 1, the percentage contribution, by continent, to global atmospheric mercury emissions is illustrated in Figure 2. It is important to note that these data do not account for emissions to water or land. Mercury used in products, such as thermostats, fluorescent lamps, and dental amalgam, is often released to landfills and sewers, or land applied (i.e. the spreading of sewage on agricultural land), and these are not accounted for in Table 1 and Figure 2. This is also true of industrial uses or byproducts of mercury that are disposed of in landfills or released directly to water bodies. As atmospheric controls on waste incinerators, steel manufacturers and other

facilities are tightened, there is an increasing trend towards the land filling of mercury waste. The fate of mercury in landfills is not well understood.

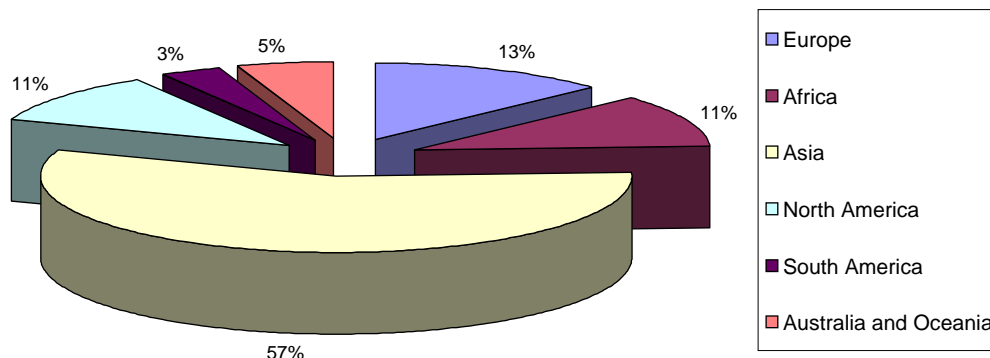


Figure 2. Percentage Contribution by Continent to Global Mercury Inventory (Adapted from UNEP, 2002)

It is estimated based on the sedimentary record that current concentrations of mercury in the environment are 1.5 to 3 times the levels they were in pre-industrial times, and that levels surrounding industrial areas have increased as much as ten-fold in the past 200 years.¹³ The best available estimates of global mercury emissions due to human activity range from approximately 2300 to 4000 metric tonnes annually, equal to approximately 70% of all emissions globally.¹⁴ The remaining 30% is estimated to be released from natural and background sources, such as volcanoes and mid-ocean venting.

Though the global mercury pool – the mercury currently existing in our air, water, and on the land – has increased in the past two decades, emissions in Western Europe and North America have steadily declined since the mid 1970’s as a result of policies designed to control mercury releases. Areas with less restrictive regulatory frameworks show trends toward increasing mercury emission. China, for example, has a significant mercury market, and releases large amounts of mercury to the atmosphere, especially as a result of coal-fired electricity generation. Emissions in China, in contrast to trends in North America and Western Europe, are estimated to have increased by 55% over the past ten years.¹⁵

Key sources of mercury emissions in North America differ depending on the region and country. In Canada, the main source of mercury releases to the environment are from the smelting industry, whereas coal-fired electricity generation facilities are the predominant emission sources in the United States; in Mexico, abandoned mercury mine tailings and losses from product disposal may be the most significant emitters.¹⁶ Gold and silver production in the United States also remains a source of mercury. Gold production in the US increased by a factor of ten between 1980 and 1998.¹⁷ Figure 3 illustrates the media into which mercury is released for Canada and the United States, as reported under the toxic reporting database in each country.

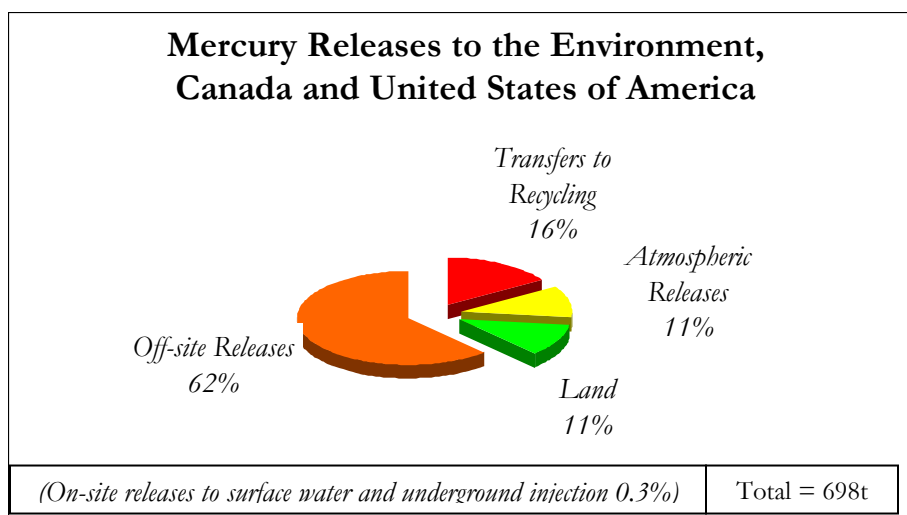


Figure 3. Mercury Releases to the Environment in Canada and the United States of America (Adapted from CEC, 2000. North American PRTR Data).¹⁸

4.1 Global Mercury Production, Use, and Flow

Mercury remains a significant global trade commodity, however production and use have been on the decline; the global mercury trade in 1990 was 2,037 tonnes, and in 1996 was reduced to 1,395 tonnes.¹⁹ Global production of mercury declined from 5,356 tonnes to 3,337 tonnes annually over the same period (Table 2). This downward trend suggests that existing frameworks regulating the commercial production, use, trade, and release of mercury are effective in the areas where they have been established, particularly in Western Europe and North America. International trade however continues and has even increased in some regions where similar restrictive policies have not been developed, particularly in developing nations where market demand persists. This fragmented political and regulatory structure has also resulted in a distinct gap in the understanding of the movement of mercury both in terms of commerce and emissions on a global scale.

Though existing mercury policies have demonstrated enormous potential for accomplishing real reductions in mercury production, use, and emissions globally, the decreased demand has created a market surplus, which has undesirable effects in areas where no policies exist to regulate mercury use. Canadian annual imports of mercury fell over 80% from 1985 to 1995, from 40-50 tonnes to approximately six tonnes over the decade. Conversely, exports rose, reaching approximately 110 tonnes in 1995 (see Figure 3).²⁰ In the United States mercury use has decreased by 95% over the past thirty years, which directly correlates to the diminished market value of 95%.²¹ The lowered value of mercury in regions where mercury use is regulated means that caches from those areas tend to flow towards regions without mercury policies.²² Typically, these are developing nations in Africa, Asia, and Latin America, where few regulations exist, and virtually no data surrounding mercury use and emissions are being gathered. The following table depicts international mercury production, use, and flow in 1990 and 1996, in metric tonnes. Figure 4 further illustrates the flow of mercury in 1990 and 1996.

Table 2. Global Mercury Production, Use, and Flow 1990 and 1996 (in metric tonnes). Adapted from Sznopce & Goonan (2000).²³

Region	Production		Use								Net flow	
			Chlor-alkali		Manufactures		Artisinal gold		Stock changes			
	1990	1996	1990	1996	1990	1996	1990	1996	1990	1996	1990	1996
North America	1,297	526	319	154	553	238	n.a.	n.a.	255	84	-170	-50
South America	0	5	72	62	65	20	200	100	34	18	371	195
West Europe	882	1,141	1,067	631	440	177	n.a.	n.a.	-	-30	-540	-363
East Europe	163	25	209	184	88	28	n.a.	n.a.	30	21	164	208
FSU	1,400	785	34	34	150	60	n.a.	n.a.	459	9	-757	-682
Middle East	47	0	101	81	35	18	n.a.	n.a.	7	5	96	104
Africa	637	347	43	36	1	9	unknown	unknown	3	2	-590	-300
India and Pakistan	0	0	138	133	66	30	n.a.	n.a.	20	16	224	179
NE Asia	930	508	0	5	375	445	unknown	unknown	1,688	701	1,133	643
SE Asia	0	0	20	24	25	36	unknown	unknown	4	6	49	66
World Total	5,356	3,337	2,003	1,344	1,798	1,061	200	100	1,335	832	-20	0

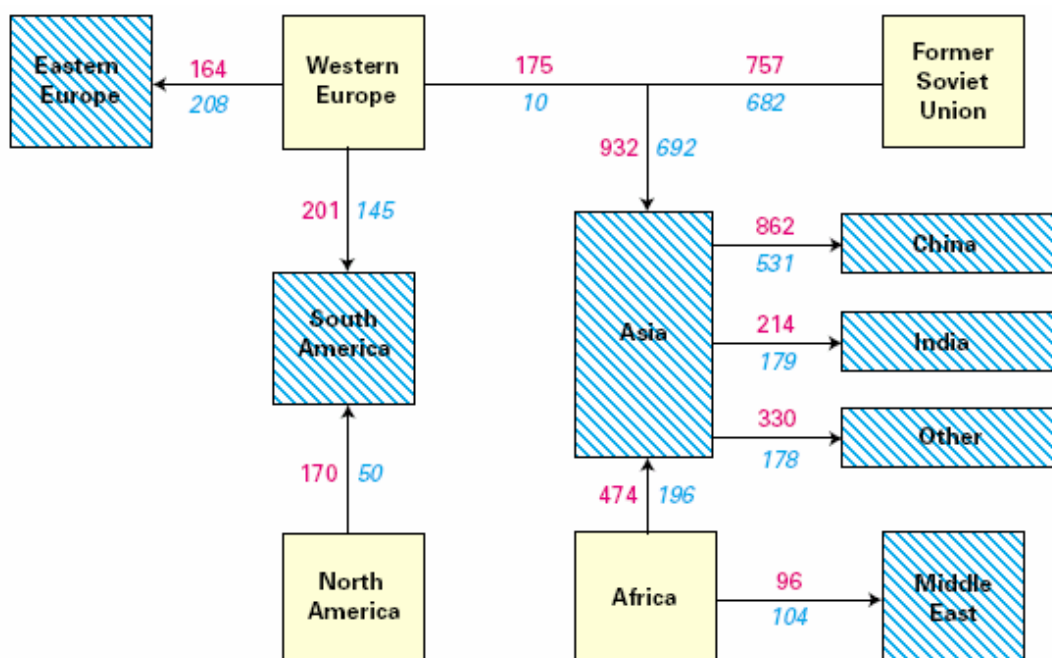


Figure 4. 1990/1996 International Net Hg Trade Flows (tonnes). Adapted from Sznopce and Goonan, (2000).²⁴

Not illustrated in Figure 4 is the source of mercury to North American market, which results from five main sources: primary mining, by-product production, mercury recovery, government reserves (US Department of Energy, and Department of Defense),

and import.²⁵ Mercury imports to North America come from government-subsidized mines in four countries: Spain, Algeria, Kyrgyzstan, and China.²⁶ Byproduct mercury production is the result of other types of mining; for example, gold and silver mining in Mexico supplies some mercury to the American market. Metal producers contribute to the available mercury supply, as do the closures of chlor-alkali factories.¹²⁷ In the United States, a handful of recent national, state, and local policies have improved the recovery of mercury from mercury-containing devices and other wastes; similar policies in Canada and Mexico are not as well developed, though Canada has improved its collection of mercury products in recent years.

Through product recycling, chlor-alkali plant closures, and other industrial by-product production, Canada and the United States produce more mercury than their markets demand, and the surplus has been made available to the global market. In response to public pressure, the United States has suspended the sale of approximately 4500 tonnes of government-held mercury as of 1994, and is currently assessing its environmental impact, and options for its disposal or sale.²⁸ Figure 5 illustrates the change in volumes of mercury imported and exported from Canada, the United States and Mexico over the early part of the 1990's. In Canada and the United States, imports of mercury are significantly less than exports. This shift can be attributed to reduced use of mercury in these countries combined with increased recovery and recycling of mercury. Less understood is the cause of the drastic decline of imports reported in Mexico since 1991.

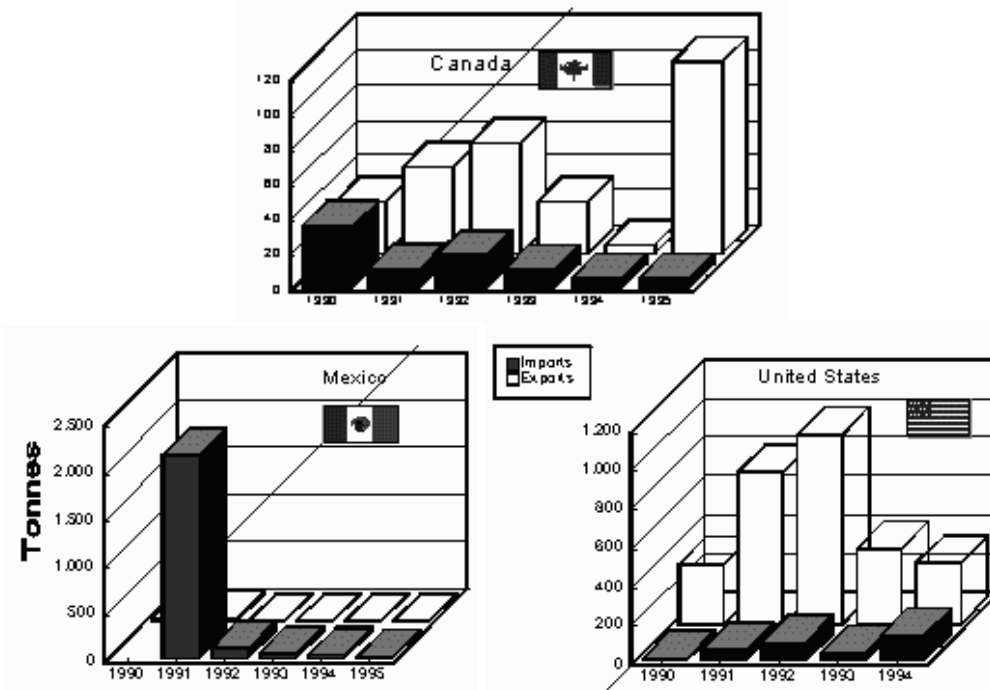


Figure 5. Mercury Imports and Exports in a) Canada, b) Mexico, and c) the United States.²⁹

¹ Mercury has been traditionally used in chlor-alkali manufacturing facilities as a catalyst in the production process. As facilities close, or move to mercury-free technology, up to 1000 tonnes of mercury per facility must be sold or disposed of. There is a great deal of discussion in many countries around the world as to the best method of addressing these periodic but significant sources of mercury to the global trade pool.

The United Nations Environment Program estimated in its market analysis that up to 900 tonnes of recycled mercury reentered the market annually as of the mid 1990's. According to Bethlehem Apparatus Company, a manufacturer of mercury switches and other devices, approximately 15 to 20% of mercury recycled from industrial scrap was done so using extractive processes in 1995.³⁰ Secondary production exceeded market demands in 1995, but has since fallen. An overall assessment quantifying the mercury-recycling sector is as yet unavailable, however, according to the Pollutant Release and Toxics Reporting data available in Canada and the United States, 11.7 tonnes of mercury is released to the atmosphere from transfers to recycling annually.³¹ While recycling mercury helps to offset emissions related to mining and smelting primary mercury, and prevents new mercury from entering both the market and the environment,³² the ready supply of mercury encourages mercury use by depreciating mercury prices.³³ Mercury retirement is an option that is being explored by a few national governments to permanently remove recovered mercury from the trade pool, and hopefully to prevent its release to the environment.

4.2 Mercury Trade Value

Mercury is a unique element, with physical and electrical properties which make it attractive for use in a variety of applications. Furthermore, mercury has always been a relatively inexpensive commodity, a factor that, along with its diverse applicability, has enhanced its appeal to the market. In 1965, at the height of demand, mercury reached an economic value of US \$2,763 for a flask containing 0.034 tonnes (value expressed in 1995 dollars to adjust for inflation).³⁴ The price has steadily declined since the mid 1970's; the same quantity of mercury was available for purchase at US \$152 in 1995.³⁵ The decline in mercury value indicates an over-supply in relation to economic demand. In 1982, the value of global mercury trade was estimated at US \$75 million, but as the market has continued to shrink, so too has the value of mercury use in commerce. Estimates from 2003 place the total trade value of mercury on the global market as low as US \$8 million.³⁶ Some of this downward trend can be associated with a more thorough understanding of the economic, environmental, and health risks associated with mercury's use.

Different forms of mercury are still in demand for a variety of commercial activities. Elemental mercury continues to be of value in small-scale silver and gold mining, chlor-alkali production, measurement and control apparatus, electrical switches, fluorescent lamps, and amalgam dental fillings.³⁷ The use of mercury compound for batteries, biocides in the paper industry, pharmaceuticals, paints, coatings for seed grain, as reagents in laboratories, and as industrial catalysts also contributes to the ongoing world trade in mercury.³⁸ In North America, mercury is no longer used in batteries, paints, or as a food-grade preservative, and its uses in many other areas has been declining. Mercury-containing batteries manufactured in other countries may be available in the North American market in small amounts, being sold under names similar to some familiar brand name batteries.³⁹

5 MERCURY POLICY

The movement of hazardous wastes, including mercury, between Canada and the United States is subject to both the Canada-United States Agreement on the Transboundary Movement of Hazardous Waste and the Organization for Economic Cooperation and Development (OECD) Decision C(92)39, which controls transboundary movements of wastes destined for recovery operations. Under the OECD decision, mercury wastes are allowed to be exported when there is no objection by the importing country. Environment Canada is responsible for controlling transboundary movement of hazardous wastes under the Export and Import of Hazardous Waste Regulations, under the Canadian Environmental Protection Act. In the United States these movements are regulated under the federal Resources Conservation and Recovery Act, overseen by the Environmental Protection Agency. Table 3 outlines current key initiatives that have impacted mercury emissions to the environment.

Canada is also a signatory to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, which came into force in 1992.⁴⁰ The Convention came out of a need to reduce or eliminate hazardous waste exports to developing countries, as industrial countries tightened their waste regulations in the late 1980's. The United States is not a signatory to the Basel Convention. Under amendments to the Convention, Canada may only export mercury waste to OECD and European Union countries, including the United States.

The United States has land disposal restrictions on mercury-bearing hazardous wastes, resulting in much of mercury waste being burned.⁴¹ Mercury is not destroyed by burning, and such burning results in the release of essentially all the mercury in the waste to the atmosphere. Ontario remains the only jurisdiction in Canada and the United States which allows land disposal of untreated hazardous wastes, though recent announcements by the Ontario government suggest these rules may be changing shortly.⁴²

Table 3 Key Initiatives Affecting Mercury Emissions

KEY INITIATIVES AFFECTING MERCURY EMISSIONS				
MAJOR APPLICATION	AGENCY	POLICY	REGION	PURPOSE/TIMING
Industrial and Product sources	United Nations Economic Commission for Europe	UNECE Heavy Metals Protocol - <i>Best Available Practices (BAP's)</i>	Global	Effective as of December 29, 2003 (Canada & UAS signed June, 1998) – reduce existing facilities emissions by 50% of 1990 values by 2011 - develop & maintain emission inventories
Mercury emissions to the Great Lakes basin	Environment Canada and the United States Environmental Protection Agency	Great Lakes Binational Toxics Strategy	Canada/ US	<i>Canada 90% reduction in GL area by 2000.</i> <i>US 50% reduction by 2006 in contiguous US</i>
Goal: to influence sources of emissions & products outside region	New England Governors/Eastern Canadian Premiers and NESCAUM	Mercury Action Plan	Eastern Canada and Eastern United States	- Implement steps to achieve 50% or greater reduction in mercury emissions in the NE region by 2003 - Virtual elimination of Hg emissions long-term
Emissions from industrial processes as well as and products	North American Commission for Environmental Cooperation	North American Regional Action Plan - Mercury	Canada, US & Mexico	<i>Phase 2 signed June 2000</i>
CWS for base metal smelters and incinerators, and for mercury-containing lamps and mercury from dental amalgam wastes already developed. A CWS for mercury emissions from coal-fired electric power generation is currently under development.	Canadian Council of Ministers of the Environment	CWS on Mercury	Canada	Reduce mercury emissions as follows: Lamps -70% by 2005, 80% by 2010 Dental Amalgam Waste -95% by 2005 based on 2000 emissions Base Metal Smelters: Existing Facilities to reduce emissions to 2g Hg/tonne, new facilities between 0.2 and 1 g Hg/tonne

6 MERCURY IN THE GREAT LAKES BASIN

The Great Lakes basin is an incredible resource that includes one-fifth of the world's fresh surface water, consists of over 244,000 square kilometres of surface water, and has a total coastline of 17,549 kilometres.⁴³ Surrounding this extensive coastline are 8 states and the province of Ontario (see Figure 6), all of which represent potential sources of harmful pollutants. The states directly adjacent to the Great Lakes account for 29% of the population of the United States, but are responsible for 36% of mercury emissions from electric power generation.⁴⁴ This is likely due to the relatively high coal consumption by Midwestern utilities.⁴⁵



Figure 6: Great Lakes basin⁴⁶

In addition, the Great Lakes basin is also subject to mercury inputs from outside the Basin. These regional emissions include, but are not limited to, those from two mercury cell chlor-alkali factories (the largest emitters of mercury on a per facility basis), taconite production – unique to Minnesota and Michigan (accounting for nearly half a tonne of annual mercury emissions), cement production, and secondary mercury production.⁴⁷ There are currently 11 mercury recovery facilities operating in the United States; the three located in the Great Lakes states produce the bulk of secondary mercury in the United States. Secondary mercury production released an estimated 0.4 tonnes of mercury in 1995.⁴⁸ There is also one manufacturer of mercury compounds located in the Great Lakes States. Numerous non-point sources also contribute to the mercury load in the Great Lakes region. More detail on mercury emissions to the Great Lakes basin by source can be found in Table 4.

Table 4 1999 Summary of Mercury Emissions to the Great Lakes by Source.⁴⁹

<i>1999 Summary of Mercury Emissions to the Great Lakes by Source</i>		
Category	Kilograms	% of Total
Electric Services (coal-fired power plants)	11,701.10	41.90
Heavy Duty Diesel Vehicles	4,322.09	15.48
Refuse Systems	2,256.74	8.08
Alkalies and Chlorine	1,244.04	4.45
General Medical & Surgical Hospitals	1,166.54	4.18
Farm Equipment	509.23	1.82
Construction Equipment	469.47	1.68
Electric and Other Services Combined	398.91	1.43
Iron Ores	390.06	1.40
Wet Corn Milling	378.94	1.36
Cement, Hydraulic	333.78	1.20
Light Duty Gasoline Vehicles	326.11	1.17
Sewerage Systems	322.75	1.16
Lamp Breakage	298.26	1.07
Gray and Ductile Iron Foundries	291.80	1.04
Sum of other categories that have emissions less than 1%	3517.82	12.58
TOTAL	27,927.64	100.00

7 IMPACTS OF MERCURY IN THE GREAT LAKES BASIN

Reduced mercury loading ultimately proffers a benefit to the health of humans and wildlife, as well as the economy.⁵⁰ Environmental impacts and market forces are typically disconnected, however. There is no financial value traditionally associated with environmental health, and no full cost accounting of environmental toxins. This makes it challenging to quantify, in monetary terms, the extent of the economic costs and benefits associated with elevated or reduced mercury emissions to the environment. The area of environmental economics is a growing field, but to date there has been little work done looking at the economic benefits of reducing mercury pollution, or the impacts of current levels in the Basin.

The economic vitality of the Great Lakes region is directly tied to the health of its people and its environment. A healthy environment supports the strength of the agriculture, forestry, tourism and outdoor recreation sectors, and healthy people mean reduced health care costs, fewer lost work days, and a stronger and more vital community. It is this premise which has contributed to the push for reduced mercury releases in the Basin. While some information exists on the ecological and health effects of mercury, these effects have not been well quantified for the Great Lakes region, and the economic costs associated with elevated mercury levels in the environment are not well studied or understood. This section of the report introduces some of the environmental and human health impacts of mercury in the Great Lakes, and identifies, where possible, some of the associated economic costs.

7.1 Human Health Impacts and Costs Related to Mercury in the Great Lakes Region

Mercury in the body has no known beneficial effect. It is an endocrine disruptor, affects neurological development and functioning, and has been associated with an increased risk of coronary heart disease and cardiovascular diseases.⁵¹ There are three forms of mercury, all of which are toxic: inorganic, elemental, and organic, one form of which is methylmercury. Exposure to mercury can occur through skin contact, inhalation or through the ingestion of mercury-bearing food. Exposure to methylmercury through food consumption is the route of primary concern for the general population, as it is this form of mercury which can accumulate in the body over long periods of time.

Inorganic and Elemental Mercury

Exposure to elemental mercury and inorganic mercury salts can occur through a variety of sources, including old paints (no longer sold in Canada and the United States), broken gas metres, workplace exposure, and through cultural practices. Exposure is typically by inhalation or skin contact. Though infrequent, mercury exposure is also possible through drinking water supplies. For instance, mercury has been detected above the maximum contaminant level for drinking water in some private wells in southern New Jersey.⁵² Mercury use in products has declined, however common household items such as thermostats and thermometers still often contain the metal. Product breakage can lead to infrequent but acute exposures to mercury, particularly if the spill is onto a rug where it cannot be effectively cleaned or in a closed environment.

The inhalation of, or contact with, mercury from mercury spills and other cases of accidental exposure can cause significant impairments to human health, including tremors, dizziness, vision problems, learning disabilities, and even death. The risks associated with mercury led the American Association of Pediatrics to recommend mercury, including mercury thermometers, not be present in the home or other environments where children are present.⁵³ Ninety-five percent of elemental mercury exposures in the United States involve broken fever thermometers.⁵⁴ The American Association of Poison Control Centers Toxics Exposure Surveillance System (TESS) indicated that in 2001, over 20,000 people were reported as being exposed to mercury, of which 7465 were children exposed to mercury from broken thermometers.⁵⁵ Over 1700 people required treatment, and approximately 20% of these cases resulted in adverse health reactions, including one death.

Mercury is still used widely in North America in dental amalgams. According to Health Canada, although dental amalgam is the largest exposure of mercury to the Canadian population, current evidence does not indicate health concerns within the general population. As a precaution, the agency recommends dental amalgam not be used in people with allergies to mercury or those with impaired kidney function, and that, whenever possible, amalgam should not be placed in or removed from the teeth of pregnant woman and the primary teeth of children.⁵⁶ In an effort to reduce the loadings of mercury to the environment from dental offices, several jurisdictions are working with dental practices and associations to achieve a 95% or greater capture rate of mercury from dental offices.

Mercury's low cost and unique properties make it an attractive material for use in a variety of products. Traditional economics however do not account for the full life-cycle

costs of these uses, including the financial, environmental, and health impacts associated with its disposal and potential emissions. Expenses related to mercury use include requirements for workplace training and safety procedures, hazardous waste handling, transport and disposal, and those associated with spills and exposure. Costs are also incurred in control measures by disposal facilities and incinerators, with expenses up to US \$2,500 to \$3,500 per kilogram of mercury captured.⁵⁷ Although the frequency of mercury spills and the associated expenses are not well documented, episodes in the health care sector have shown that the price tag for mercury spills can be very expensive. For instance, Butterworth Hospital in Grand Rapids, Michigan, estimated an average cost of US\$3,000 per spill.⁵⁸ One New Hampshire hospital reported cleanup costs for mercury spills in 1998 to be US \$130,000.⁵⁹

A 1996 Ontario study of the use of mercury in hospitals showed that phasing-out the use of mercury products will save the facilities money, even though alternatives were in some cases initially more expensive.⁶⁰ The report took into account costs such as hazardous waste training, mercury spill clean up, waste storage and disposal, and potential health risks to staff, patients, and visitors. The indirect environmental and health costs were not quantified. For one sphygmomanometer, or blood pressure cuff, the cost for a mercury device including incidentals and indirect costs is on the order of \$600 to \$1100; a non-mercury alternative costs just \$300, with no additional charges.⁶¹ It is reasonable to expect similar results for the life-cycle costs of many mercury-containing products.

The use of mercury-containing switches in vehicles has all but ceased, at least partly due to a consideration of full-cost accounting. The United States Environmental Accounting Project reported that one vehicle manufacturer in the US began removing or replacing mercury switches with alternatives, after applying the principle of environmental accounting. The company determined that it could cost-effectively replace the switches with a ball-bearing type switch, and in doing so avoid the costs associated with end-of-life vehicle disposal and avoidance of liability issues.⁶²

Methylmercury

While all forms of mercury are toxic, it is exposure to methylmercury which is of greatest concern in Canada and internationally. Mercury released into the atmosphere from human or natural means often finds its way into lakes, rivers, and wetlands where bacteria convert it to methylmercury, the organic form of the metal. Methylmercury has three properties which make it toxic: it is persistent, it bioaccumulates, and it is toxic to most life forms. Methylmercury biomagnifies in the aquatic ecosystem, meaning its concentrations increase up the food chain, resulting in sometimes dangerously high levels in predatory fish. Humans and other animals that eat these fish are then at risk of mercury poisoning. Consumption of methylmercury-tainted seafood, freshwater fish, and shellfish are the primary pathways for methylmercury exposure for the general population.⁶³ Concern is greatest for vulnerable segments of the population, including pregnant women, children and certain ethnic communities who consume large amounts of seafood, such as Aboriginal and Native American people.⁶⁴ Government and independent health bodies have long recognized the risks to human health from eating fish from the Great Lakes contaminated with mercury. Recent studies however indicate observable health effects occur at lower chronic levels of exposure than previously thought. The Centers for Disease Control and Prevention reported as many as 375,000 children born each year in the US alone are at risk of neurological development problems as a result of

maternal consumption of mercury-contaminated fish, and that one in 12 women of childbearing age had mercury blood levels in excess of those considered safe by the US EPA.⁶⁵ No similar reporting has been done for Canada or the Great Lakes basin, however these numbers illustrate the magnitude of mercury's impact on the North American population as a whole.

The risk associated with mercury toxicity can create undue hardships, not only to the individuals and families who suffer the effects of mercury contamination, but also to the economy at large, through increased education and health costs, and reduced productivity. For instance, mercury exposure in pre-natal or young children has been associated with such impacts as learning disabilities, which appears to be on the increase in North America. Cincinnati Public Schools, for example, provided approximately 12 percent of their students with special needs education in 1999, almost double the 6.2 percent ten years earlier.⁶⁶ Over the same ten-year span special education needs increased by approximately 1.6% in the US. Education costs for a learning disabled child is approximately double that of the average student. Mercury of course is one of only a host of risk factors for these and other disorders; estimating the portion of these costs which are a result of mercury exposure may be impossible, however it is important to understand the magnitude of the impacts which are being felt in society to which mercury exposure is a contributor.

For Great Lakes fish with mercury levels in excess of health guidelines, the historical policy response from governments has been the issuance of fish advisories that inform anglers of which fish are safe to eat. While important, there are many limitations to this system that can lead to frequent human exposure to mercury above health guidelines. For instance, fish advisories are not standard across the Great Lakes, due to different interpretations of safe levels of mercury exposure. Research has shown that many anglers either ignore fish advisories or are unaware of them.⁶⁷ This is particularly true for women and ethnic communities. Women make up 44% of Great Lakes fish consumers from the Great Lake states, and many ethnic communities traditionally consume high volumes of fish.⁶⁸ A Health Canada study found that in 1996-97 only one-third of the people eating fish from heavily contaminated waters in Ontario used the province's sport fish consumption guide. The Federal Environmental Commissioner criticized Health Canada for failing to properly communicate the risks to fish consumers.⁶⁹

The commercial sale of Great Lakes fish with elevated levels of mercury is also a concern. Consumers purchasing fish from markets or restaurants are even less likely to be aware of fish advisories, and, unlike anglers, often don't know enough about fish terminology to interpret fish advisories properly.⁷⁰ Some independent testing in 2001 on fish caught from Lake Huron showed several fillets approached or even exceeded Health Canada guidelines for mercury.⁷¹ Despite this, fish from the lake sold in commercial markets had not undergone testing for chemical contaminants since at least 1996. The Canadian Food Inspection Agency admitted in 2001 that commercial fishing licenses in Lake Huron are being granted based on science that needs updating.⁷² According to the Great Lakes Science Advisory Board, recent research on methylmercury in fish and human health suggests that current advisories are outdated, and may not be protecting public health.⁷³ Approximately 4.7 million people in the Great Lakes states eat Great Lakes fish⁷⁴, and 37% of Ontario's population participates in sports fishing an average of 5 times per year.⁷⁵ Given the health impacts of even low levels of mercury exposure, the

importance of up-to-date and well-communicated advisories cannot be understated. The long-term goal however must be the reduction of mercury levels in fish in the Great Lakes.

The complexities associated with mercury exposure are too great, and current information too sparse, to allow accurate quantification of the economic costs associated with its impacts on humans. There are many challenges to assessing the link between mercury exposure and neurological effects, including individual biological differences, latency between exposure and onset of symptoms, and synergistic effects of multiple pollutants. A compounding factor is the inadequate information on current mercury levels in sports fish and consumption data for fish.⁷⁶ What research has been done on the linkage between disease and pollution, including mercury, indicates the cumulative health care costs across the Great Lakes regions are in the billions of dollars.⁷⁷

7.2 Impacts of Mercury on the Great Lakes Environment

Mercury has been identified as a teratogen, mutagen, and carcinogen, and the cause of a variety of behavioral effects in wildlife.⁷⁸ Determining the impact of mercury on Great Lakes ecosystems is challenging, particularly when examining low level effects, which are often subtle and may take years to surface.⁷⁹ In some instances, analytical detection levels used in monitoring programs are above the concentrations where biological effects occur, making the science even more challenging.⁸⁰

Years of industrial discharge and atmospheric deposition of mercury have elevated mercury levels in the Great Lakes beyond natural background levels. In some regions, mercury levels are high enough to impair several of the uses of the Great Lakes, including restrictions on fish consumption by humans, restrictions on dredging activities, and impairment of water and sediment quality.⁸¹ Mercury concentrations in occasional samples of water, sediment, sport fish, and biota of Lakes Superior, Erie, and Ontario; the St. Mary's River System; and the St. Clair/Detroit River System have often exceeded the current Provincial Water Quality Objectives and the Great Lakes Water Quality Agreement. Similarly, concentrations in sediment and biota in Lake Huron, the Niagara River, and the St. Lawrence River have also exceeded the current criteria.⁸²

No formal program exists as yet for gathering the necessary long-term environmental health effect data to quantify the ecological impacts of mercury in the Great Lakes basin.⁸³ While further research is needed, risks have been clearly identified for birds, fish, and mammals.⁸⁴ Traditionally thought of as a vector for human exposure to methylmercury, fish populations themselves are subject to the detrimental effects of mercury exposure. Even relatively low concentrations of mercury and methylmercury in water and fish tissues have been linked to increased mortality, decreased growth, sluggishness, poor reproduction and deformities.^{85,86}

Mercury's effect on birds is well documented, particularly on loon and birds of prey and in eastern North America. Consumption of mercury-contaminated fish by piscivorous birds and mammals is a known vector for mercury poisoning. At least one loon death in Nova Scotia has been linked directly to the toxin.

7.3 Effect of Reducing Mercury Contamination

Reduction or elimination of a contaminant source will result in a general decline in that contaminant's levels in the ecosystem, including the fish.⁸⁷ A recent Florida study demonstrated declining mercury levels in the ecosystem as a result of years of efforts to curtail emissions.⁸⁸ This trend has been noticed for mercury in the Great Lakes since the direct discharges from major industrial sources in the 1960's and 1970's have been substantially reduced.⁸⁹ With continued reductions this trend should continue.

As a specific example, Figure 7 below is a graph of mercury concentration in a 45cm walleye in Lake St. Clair from 1970 to 1997. Lake St. Clair was heavily contaminated by mercury discharges from an industrial plant in 1970. Since that point, mercury levels have decreased dramatically and many sizes of sport fish can now be consumed without restrictions.⁹⁰ Figure 8 shows both the positive correlation between mercury concentration and fish length, and the decreasing trend of mercury concentrations in largemouth bass in Rice Lake, Ontario.

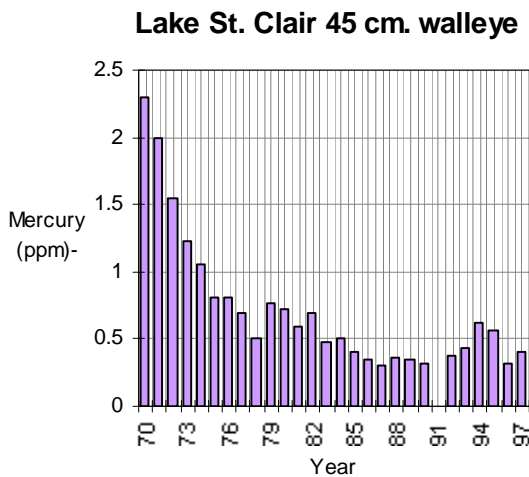


Figure 7

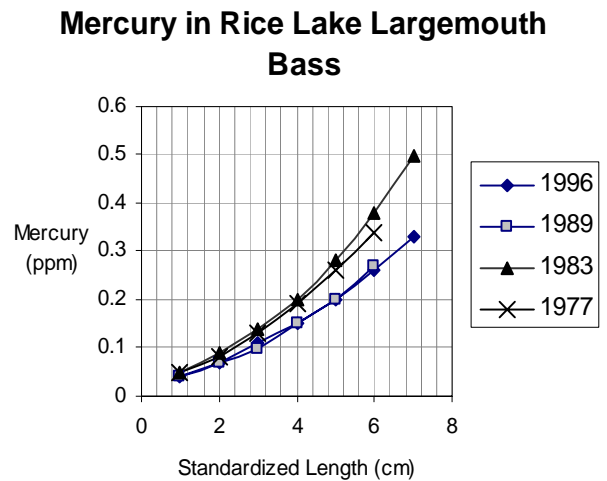


Figure 8

Figures 7 and 8 adapted from 1999-2000 Guide to Eating Ontario Sport Fish (1999)

Canadian and US mercury releases in the Great Lakes basin have been cut by more than 11 tonnes since 1988, through a combination of changes in industrial technology (i.e. for chlor-alkali plants and metal smelters) and a decrease in the deliberate use of mercury. Mercury has been eliminated from virtually all paints and batteries, and its use decreased in other industrial and consumer products.

8 ECONOMIC CONSEQUENCES OF MERCURY TO GREAT LAKES TOURISM AND FISHERIES

The Great Lakes is the major recreation and tourism attraction in the United States, and one of the pre-eminent tourism areas in North America.⁹¹ During the winter months the lakes are home to ice fishers and skiers, and the summer months bring millions of people to the beaches, rivers, and out into the lakes themselves. Tourism, recreational and commercial fisheries are some of the largest economic sectors in the region.

"The Great Lakes attracted 2.5 million anglers in 1991; nationally, anglers fished an average of 14.5 days and spent an average of \$728 per person on their sport. This equates to about \$1.8 billion in annual economic impact in the Great Lakes region."⁹²

Ontario parks around the Great Lakes drew 11 million visitors in 2001, with tourism generating over CDN\$ 20 billion.⁹³ Fifteen million people partake in hunting, fishing, and wildlife observation annually in the US states bordering the Great Lakes, generating a further US\$ 18.5 billion in sales. Sports fishing accounts for over one quarter of the tourism-related expenditures in the western Great Lakes, and CDN\$ 1.7 billion annually for Ontario's economy. Close to 2 million fishing licenses were issued in Ontario alone in 1995.⁹⁴ The estimated value of the Lake Ontario sports fishing industry on both sides of the lake is CDN\$136.8 million.⁹⁵

The presence of elevated mercury levels in the Great Lakes has the potential to impact the recreational and commercial fishery industry, and tourism, in the region.⁹⁶ A decline is already taking place; according to a 1996 US Fish and Wildlife survey, 41,000 people restricted their fishing activities because of pollution.⁹⁷ Several government and independent bodies have noted the potential for negative economic consequences of fish advisories caused by mercury contamination.⁹⁸ Inherently, this means there are conflicting interests within the Great Lakes. Developing advisories is not a simple matter and conflicts arise over both the economic impacts as well as the risk message. Commercial fishing interests and those with an economic interest in recreational fishing, anglers and subsistence fishers, and governmental agencies, may have non-intersecting interests.⁹⁹

The International Joint Commission estimated income losses due to persistent-toxic related closures or market losses in the Great Lakes region, with some alarming results. Losses in the early 1990's due to mercury in Lake St. Clair were approximately \$5 million per year; mirex contamination in Lake Ontario caused \$2 million per year of losses; and persistent toxic substances in Lake Ontario carp and mirex in sports fish caught for sale at about \$1.5 million per year.¹⁰⁰ Revenue losses were due to such factors as reduced numbers of fishing trips, lost value in the commercial fishery due to exceedences in allowable mercury concentration, and reduced demand for fish due to perceived health threat.

The first sports fish advisory was issued for Great Lakes fish consumers in 1971.¹⁰¹ There are currently 45 states and eight provinces with fish advisories for mercury, including some which blanket all water bodies within those jurisdictions. Mercury is responsible for anywhere from 22% to 66% of fish consumption advisories in the Great Lakes and Lake St. Clair region. This means that while other contaminants may be the

limiting factor in many advisories, mercury can still be present and the dominating contaminant in some cases.¹⁰²

In many cases the recent increase in fish advisories is due not to increasing levels of mercury but to tighter guidelines for mercury-contaminated fish. There is concern by many agencies that the presence of fish advisories will cause economic hardship to those working in the recreational fishing industry, and beyond. Several areas of the economy could be affected by reduced participation in the recreational fisheries industry: sales of food, lodging, gasoline, sporting equipment. They may accurately or inaccurately alter the public's perception of the fishery, potentially causing an overreaction to the issue and a further decline in the industry. Also a concern is the potential conflicting messages being sent to the public and particularly to subsistence fisher-people of the health benefits and costs associated with fish consumption. Fish is an important food and nutrient source for many individuals and communities, and there are risks associated with replacing fish consumption with other foods which are potentially higher in saturated fats, salts, and which provide less nutritional value.

Testing the effects of advisories on the general population's fishing activities is difficult at best. Studies that have shown anglers are unaware of advisories or chose to ignore them do not identify those individuals who chose not to fish because of health concerns. There are many ways individuals may assess their risks with respect to fish consumption advisories, including:¹⁰³

- Remaining unaware
- Being aware but ignoring such information
- Reaching a decision that it is not a problem for them
- Reducing or changing their consumption patterns
- Continuing to fish but catch and release
- Stopping fishing

The Great Lakes Science Advisory Board suggests that the largest impact from fish advisories will be to deter those who have not participated in the fishery from partaking in the activity, while those for whom fishing is a long-term hobby will rely more on personal experience and be less likely to be scared off by the presence of advisories or word-of-mouth information.¹⁰⁴ The total losses associated with elevated mercury levels are difficult to gauge, since many people practice catch and release and therefore may not be concerned about contamination, and because it is difficult to locate and talk to those people who have decided not to participate in fishing due to mercury or other pollution.

9 CONCLUSIONS

Mercury is a unique and pervasive substance which on a global scale has been increasing in the environment through such activities as mining, smelting, burning of fossil fuels, and as a result of its deliberate use in various products and processes. Mercury exists in many forms, however it is methylmercury, an organic form which bioaccumulates in the food chain, which has caused the most concern with respect to both human and ecosystem health.

There have been significant reductions in both emissions and concentrations of mercury in the Great Lakes basin over the past few decades, a result of both reductions in the use

of mercury and of direct industrial discharge of the toxin to basin water bodies. However, both the Canadian and United States governments have acknowledged that despite efforts and commitments, releases of mercury continue on both sides of the border, to the detriment of the Great Lakes environment.

The economics associated with mercury use in products and processes make it challenging to restrict the use and release of the metal. Full lifecycle costing, including the environmental and health impacts of mercury in the Great Lakes basin, has not been done. Policy initiatives would profit from completing cost-benefit analyses that consider mercury's externalities such as waste disposal and control costs, medical costs, lost workdays, increasing demand on special needs classrooms, and potential losses to the fishing and tourism-related economies.

The issuance of fish advisories has been adopted around the Great Lakes as an interim measure to limit human consumption of contaminated fish, and prevent potential health impacts. While such warnings are prudent, and help to limit exposure to methylmercury, the long-term goal must continue to be focused on the restoration of the basin's ecological integrity. Through sustained action on both sides of the border, the costs to human and wildlife health, society, our medical system and our economy will continue to decline. Ultimately, only the reduction of mercury inputs to the ecosystem has the potential to avert future impacts to human and environmental health in the Great Lakes basin. With further effort, the current decreasing trend of mercury in the basin will continue, and background levels may eventually be reached.

ENDNOTES

-
- ¹ Pilgrim, W., M. Lucotte, S. Montgomery, C. Santos-Burgoa, M. Uriarte, F. Abascal-Garrido, M. Round, D. Porcella. (1999) *Meeting the Challenges of Continental Pollutant Pathways: Mercury Case Study*. Ecological Monitory Assessment Network. http://eqb-dqe.cciw.ca/eman/reports/publications/99_mercurywkshp/page4.html. Accessed Nov. 2003.
- ² Mittlestaedt, M. 2003. *Mercury is a Global Problem, US Says*. Globe and Mail, February 4, 2003.
- ³ United Nations Environment Program: Chemicals. 2003. *Global Mercury Assessment*. Geneva, Switzerland. http://www.unon.org/css/doc/gc22/GC22_inf/inf3_e.pdf
- ⁴ *ibid.*
- ⁵ *ibid.*
- ⁶ Bloxam, R. 1995. *Modeling Mercury Atmospheric Transport, Chemistry, and Deposition*. <http://www.eman-rese.ca/eman/reports/publications/mercury95/part16.html>
- ⁷ *ibid.*
- ⁸ Lourie, B., 2001. *Presentation to the EPPC/DC*. Pollution Probe, Ontario.
- ⁹ *ibid.*
- ¹⁰ National Pollutant Release Inventory. 2001. <http://www.ec.gc.ca/pdb/querysite/html/queryform.cfm> Accessed November 14, 2003.
- ¹¹ National Pollutant Release Inventory (NPRI). *The Four New Groupings of ATH Substances - Substance-Specific Context: Mercury and its compounds*. http://www.ec.gc.ca/pdb/npri/npri_mercury_e.cfm, accessed Nov. 2003.
- ¹² Pilgrim, et al., 1999. *op cit.*
- ¹³ *ibid.*
- ¹⁴ Mason, R., Fitzgerald, W. and Morel, F., 1994. The biogeochemical cycling of elemental mercury: anthropogenic influences. *Geochim. Cosmochim. Acta*. 58: 3191-3198.
- ¹⁵ Seigneur, Christian, 2003. *Review: Mercury*. Global Emissions Inventory Activity <http://geiacenter.org/reviews/mercury.html>, accessed Nov. 2003.
- ¹⁶ Pilgrim, et al., 1999. *op cit.*
- ¹⁷ *ibid.*
- ¹⁸ Adapted from CEC, 2000. *North American PRTR Data*
- ¹⁹ Sznoppek, John L. and Thomas G. Goonan, 2000. *The Materials Flow of Mercury in the Economies of the United States and the World*. US Department of Interior, and US Geological Society, Denver, Colorado. <http://pubs.usgs.gov/circ/2000/c1197/c1197.pdf>
- ²⁰ Pilgrim, et al., 1999. *op cit.*
- ²¹ QSC/EPA Mercury Stewardship Workgroup, 2003. *Mercury Commodity Market Review*. <http://www.sso.org/ecos/Quick%20silver%20documents/RD-QSC%20%20MARK%20FACTS%20Feb-03.pdf>
- ²² QSC/EPA, *op cit.*
- ²³ Sznoppek, John L. and Thomas G. Goonan, 2000. *The Materials Flow of Mercury in the Economies of the United States and the World*. US Department of Interior, and US Geological Society, Denver, Colorado. <http://pubs.usgs.gov/circ/2000/c1197/c1197.pdf>. Accessed Nov 2003.
- ²⁴ Adapted from Sznoppek and Goonan, (2000). *op cit.*
- ²⁵ Pilgrim, et al., 1999. *op cit.*
- ²⁶ QSC/EPA, *op cit.*
- ²⁷ QSC/EPA, *op cit.*
- ²⁸ *ibid.*
- ²⁹ Pilgrim, et al., 1999. *op cit.*
- ³⁰ US EPA and EC, 1999. *Draft Report: Mercury Sources and Regulations*. <http://www.epa.gov/glnpo/bns/mercury/17>. Accessed Nov. 16, 2003.
- ³¹ CEC, 2000. *North American PRTR Data* <http://www.cec.org/files/pdf/POLLUTANTS/Mercury2000a.pdf>
- ³² UNEP, 2003. *op cit.*
- ³³ QSC/EPA, *op cit.*
- ³⁴ *Mercury Stewardship: Mercury Commodity Market Review – Review Draft*. 2003. <http://www.sso.org/ecos/Quick%20silver%20documents/RD-QSC%20%20MARK%20FACTS%20Feb-03.pdf>
- ³⁵ *ibid.*

-
- ³⁶ An estimate based on 4000 tons mercury at \$2/lb.
- ³⁷ UNEP, 2003. op cit.
- ³⁸ *ibid.*
- ³⁹ Esaki, Eiji . President of Panasonic Canada. September 2002, Personal communication.
- ⁴⁰ Basel Convention on Long Range Transport. (Online). www.basel.int. Accessed: November 16, 2003.
- ⁴¹ Bender, M. 2000. Collecting Mercury-Containing Products in North America: Model Programs, Identifying and Overcoming Barriers, and Transboundary Requirements. A Report to the Commission for Environmental Cooperation, prepared by the Mercury Policy Project (A Project of the Tides Center).
- ⁴² Ontario Government website. www.gov.on.ca. Accessed November 19, 2003.
- ⁴³ *ibid.*
- ⁴⁴ US EPA and EC, 1999. op. cit.
- ⁴⁵ *ibid.*
- ⁴⁶ Great Lakes Information Network. *Great Lakes Overview*. <http://www.great-lakes.net/lakes/#overview>, accessed Nov., 2003.
- ⁴⁷ *ibid.*
- ⁴⁸ *ibid.*
- ⁴⁹ Great Lakes Commission, 1999. *1999 Inventory of Toxic Air Emission: Point and Area Sources*. <http://www.glc.org/air/inventory/1999/99toc.pdf>
- ⁵⁰ Hagen, D., J. Vincent, and P. Welle. 1999. *Economic Benefits of Reducing Mercury Deposition in Minnesota*. Prepared for the Minnesota Pollution Control Agency and The Legislative Commission on Minnesota Resources.
- ⁵¹ National Academy of Sciences. 2002. *Toxicological Effects of Methylmercury*. National Research Council. National Academy Press, Washington, DC.
- ⁵² New Jersey Mercury Task Force. January 2002. *Mercury Task Force Report, Volume 2: Exposure and Impacts*. (Online) http://www.state.nj.us/dep/dsr/mercury_task_force.htm. Accessed: Nov. 11, 2003.
- ⁵³ Goldman, L. M. Shannon, and the Committee on Environmental Health. 2001. Technical Report: Mercury in the Environment: Implications for Pediatricians (RE109907). The American Association of Pediatricians. *Pediatrics*. 108(1): 197-205, 2001.
- ⁵⁴ Palladino, A., RPh. 1997. Mercury Poisoning. Personal Communication.
- ⁵⁵ American Association of Poison Control Centers. 2002. 2001 Toxic Exposure Surveillance System Annual Report. *The American Journal of Emergency Medicine* 20(5):391-452, 2002.
- ⁵⁶ Health Canada news release. *The Safety of Dental Amalgam: Health Canada states position*. August 21, 1996. http://www.hc-sc.gc.ca/english/media/releases/1996/96_63e.htm (accessed November 15, 2003).
- ⁵⁷ Lourie, et al., 1996. op cit.
- ⁵⁸ Stickles, 1994. In Lourie et al., 1996. op cit.
- ⁵⁹ Sustainable Hospitals Project. *Mercury Spill Costs*. (Online) www.sustainablehospitals.org/PDF/IP_spills_costs.pdf. Accessed: Nov. 14, 2003. Lowell Center for Sustainable Production, University of Massachusetts.
- ⁶⁰ Lourie et al., 1996. op cit.
- ⁶¹ *ibid.*
- ⁶² UNEP, 2003. op cit.
- ⁶³ Northeast States for Coordinated Air Use Management. 2003. *Mercury Emissions from Coal-Fired Power Plants: The Case for Regulatory Action*.
- ⁶⁴ Hageen, L. 2001. Mercury Rising. *Encompass*. December 2001 Issue. 5(7):6-7, 2001.
- ⁶⁵ Centers for Disease Control and Prevention. 2001. *Report: Exposure to Environmental Chemicals*.
- ⁶⁶ DiFilippo, Dana, 1999. *Special Needs Multiplying*. *Enquirer*, http://www.enquirer.com/editions/1999/09/26/loc_special_needs.html
- ⁶⁷ New Jersey Mercury Task Force. January 2002. *Mercury Task Force Report, Volume 2: Exposure and Impacts*. (Online) http://www.state.nj.us/dep/dsr/mercury_task_force.htm. Accessed: Nov. 11, 2003.
- ⁶⁸ Knuth, 1995. and Tilden et al, 1997., cited in Great Lakes Science Advisory Board. 2001. 1999-2001 Priorities Report, Chapter 2.
- ⁶⁹ Lourie, et al., 1996. op cit.

-
- ⁷⁰ NJ Mercury Task Force, 2002. op cit.
- ⁷¹ The Stratford Beacon Herald, Nov. 16, 2001. "Data on chemical contaminants on Lake Huron fish outdated: expert", page 7.
- ⁷² The London Free Press, Nov. 14, 2001. "Lake Huron fish testing under fire", page B5.
- ⁷³ Great Lakes Science Advisory Board, 2001. op cit.
- ⁷⁴ Tilden et al., 1997. op cit.
- ⁷⁵ Usher et al., 1987, in Great Lakes Science Advisory Board, 2001. op cit.
- ⁷⁶ National Wildlife Federation, no date. op cit; NJ Mercury Task Force, 2002. op cit.
- ⁷⁷ Great Lakes Science Advisory Board, 2001. op cit.
- ⁷⁸ Eisler, 1987. Cited in NJ Mercury Task Force, 2002. op cit.
- ⁷⁹ NJ Mercury Task Force, 2002. op cit.
- ⁸⁰ Great Lakes Science Advisory Board, 2001. op cit.
- ⁸¹ Ontario MOEE, 1992. cited in Lourie et al., 1996. op cit.
- ⁸² Ontario MOEE. 1992. cited in Lourie et al., 1996. op cit.
- ⁸³ Great Lakes Science Advisory Board, 2001. op cit.
- ⁸⁴ Eisler, 1987. op cit.
- ⁸⁵ NJ Mercury Task Force, 2002. op cit.
- ⁸⁶ Northeast States for Coordinated Air Use Management. 2003. Mercury Emissions from Coal-Fired Power Plants: The Case for Regulatory Action.
- ⁸⁷ Government of Ontario. 2000. *1999-2000 Guide to Eating Ontario Sport Fish 20ed. revised.* Queen's Printer for Ontario.
- ⁸⁸ Florida Department of Environmental Protection. 2002. *Integrating Atmospheric Mercury Deposition with Aquatic Cycling in South Florida: An approach for conducting a Total Maximum Daily Load analysis for an atmospherically derived pollutant.* October, 2002, Revised Nov., 2003.
- ⁸⁹ Government of Ontario. 2001. *2001-2002 Guide to Eating Ontario Sport Fish 21ed. revised.* Queen's Printer for Ontario.
- ⁹⁰ Government of Ontario. 2000. *1999-2000 Guide to Eating Ontario Sport Fish 20ed. revised.* Queen's Printer for Ontario.
- ⁹¹ Kling, G. 2003. *Confronting Climate Change in the Great Lakes Region, Chapter 1: Great Lakes Ecosystems and People: Mutual Influence and Dependence.* Union of Concerned Scientists and The Ecological Society of America.
- ⁹² US Fish and Wildlife Service, 1992. cited in Lourie et al., 1996. op cit.
- ⁹³ Kling, G. 2003. op cit.
- ⁹⁴ National Wildlife Federation, no date. op cit.
- ⁹⁵ Environment Canada. Backgrounder: Lake Ontario Invasion Begins "Round Gobies" Feed on Sport Fish Eggs, Zebra Mussels (Online) <http://www.on.ec.gc.ca/press/goby-invasion.html>. Accessed: Nov. 23, 2003.
- ⁹⁶ National Wildlife Federation, no date. op cit.
- ⁹⁷ National Wildlife Federation, no date. op cit.
- ⁹⁸ Wisconsin Mercury Citizen Advisory Committee. February 2002. *Priority Table, Version 2/8/2002.* (Online) <http://www.dnr.state.wi.us/org/aw/air/reg/mercury/rule.htm>. Accessed date: November 14, 2003.
- ⁹⁹ New Jersey Mercury Task Force, 2002. op cit.
- ¹⁰⁰ International Joint Commission, 1993. cited in Great Lakes Science Advisory Board. 2001. op cit.
- ¹⁰¹ Great Lakes Information Network. Great Lakes fish and fishing. (Online) http://www.great-lakes.net/teach/envt/fish/fish_1.html. Accessed date: November 23, 2003.
- ¹⁰² Government of Ontario. 2001. op cit.
- ¹⁰³ Great Lakes Science Advisory Board. 2001. op cit.
- ¹⁰⁴ *ibid.*