PRIORITIES

2001-2003

Priorities and Progress under the Great Lakes Water Quality Agreement

September 2003

ISBN 1-894280-40-7

Report to the International Joint Commission by the

Great Lakes Science Advisory Board
Great Lakes Water Quality Board
Council of Great Lakes Research Managers
International Air Quality Advisory Board

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INTRODUCTION

In the *Great Lakes Water Quality Agreement*, the United States and Canada commit "to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem."

A fundamental role of the International Joint Commission (IJC) is to evaluate the governments' progress in implementing the *Great Lakes Water Quality Agreement*, identify unmet challenges, and recommend solutions. The IJC provides a report at least every two years that presents its findings, advice and recommendations to governments.

From 2001-2003, several IJC advisory boards and council have focused on a discrete set of high priorities assigned to them by the Commissioners. The results of two years of intensive work are presented herein to the Commission, for their consideration as they develop advice to governments and report to the public through their *Twelfth Biennial Report on Great Lakes Water Quality*.

This *Priorities Report* conveys a wealth of information and state-of-the-art analyses of select research, scientific and policy arenas that are fundamental for advancing stewardship of the Great Lakes basin ecosystem.

Chapter One begins with a discussion of science substantiating that toxic chemicals cause harm to both mental and reproductive function in fetuses and adults. The IJC was among the first of the international organizations to focus on the presence, transport and effects of persistent toxic substances in the environment. In this priority cycle, the Commission's request that its boards focus on mercury has proved most timely, as large reductions in emissions from coal fired utilities are now under consideration in both the United States and Canada. Herein you will find the most current science surrounding mercury, compelling evidence of its neurotoxic properties, and an exposé on the risks associated with consumption of contaminated fish. To guide the formulation of programs and policies that could reduce the inputs of mercury to the basin ecosystem, the complex atmospheric dynamics of mercury are treated in detail here as well.

Chapter Two provides specific advice to the Commission on aspects of Annex 2 — Remedial Action Plans (RAPs) in particular. It explores the question of how to accelerate RAP implementation and consequently, the restoration of beneficial uses. To paraphrase some of the analyses, when we set out on a voyage, we have a choice. We can follow impulse and spontaneity, or we can take a map that leads us to a particular destination. The map is akin to the Remedial Action Plan, and it must contain coordinates for the destination. To answer the question, *"Where is There?"* RAP participants need information that will enable them to recognize when the Area of Concern achieves the goals and uses formulated by the community. Rehabilitation targets, referred to as delisting criteria or endpoints are essentially the coordinates for the destination. These targets enabled the team to prioritize actions and to interpret the road signs that direct progress toward the restoration of beneficial uses. Specific advise contained here, on the design and execution of RAPs should illuminate all readers, particularly those associated with an Area of Concern.

Chapter Three tackles urbanization and the complex land use-water quality linkages. The *1997-99 Priorities Report* noted that "Urbanization in particular has brought significant changes to natural systems, particularly in increased land surface imperviousness." These issues were revisited in the *1999-01 Priorities Report* and are further probed here. Urbanization not only threatens Great Lakes water quality by pollutants in waste water discharges, but also degrades surface water through excessive stormwater flows. Beach closings and impaired recreational water quality result. Urban sprawl can destroy wetlands. Subdivisions fragment habitat. Our increased use of vehicles pollutes the air, the land and the water. Increases in impervious surfaces associated with highways, buildings and parking lots increase runoff, exacerbating nonpoint source pollution in our rivers and waterfronts. This chapter explores water quality impacts and policy implications surrounding the reality of growth and the necessity to preserve the quality of life. In this chapter you will find intriguing examples of innovative principles to guide policy development and implementation.

Chapter Four considers the impacts of climate change on water quality in the Great Lakes basin. Priority work on this issue is still in progress. The fundamental questions being explored concern the types of water quality impacts that might be the consequence of more severe storm events and warmer temperatures, how the impacts might vary across Great Lakes regions, and the implications for decision making and planning to respond to or mitigate the impacts. The importance of climate change on ground water resources is particularly noted, in light of drought conditions, low precipitation and increasing average temperatures. These themes are not often front and center in the minds of basin residents and are particularly foreboding.

Chapter Five presents the outcome of an expert consultation on emerging issues in the Great Lakes. A compelling, perhaps unanticipated finding, was that while there are clearly many threats to the health of the basin ecosystem, no new, previously unknown threats to the Great Lakes were identified by the scientific experts consulted. This curiously suggests that existing and anticipated threats may be due to our current inability to adequately address ecosystem quality. In this regard, the specific findings and recommendations emphasize the need for greater binational institutional capacity, reinvigorated management and governance structures to fully implement an ecosystem approach to the protection and restoration of the lakes, a clear and unmistakable call for leadership and coordination.

Chapters Six, Seven and Eight include additional reports from the boards and council on a range of other topics that are brought together to enlighten and advise the Commission and the reader. Current research into the changing dynamics in Lake Erie and outbreaks of botulism are described. Health implications of persistent toxic chemicals are reviewed. In particular, the finding that PCB levels in water and fish of the Great Lakes must decrease by one to three orders in magnitude to achieve state and federal levels for protection of public health is a call for action. The latest research and research needs regarding sources and effects of pathogens and new chemicals of concern are presented. All these topics are highly relevant if our efforts to understand, protect and enhance the majesty of the Great Lakes are to be successful.

About the Authors of the Report

The principal advisor to the IJC, the **Water Quality Board** comprises 20 program managers and administrators from the two federal governments, the eight states and two provinces in the Great Lakes - St. Lawrence River basin. The **Science Advisory Board**, whose 18 members represent a broad range of disciplines, provides scientific advice to both the IJC and Water Quality Board.

The **Council of Great Lakes Research Managers** has 23 members who provide advice related to the coordination and evaluation of Great Lakes research efforts. Given the significance of the air as a pathway by which contaminants reach the waters of the Great Lakes, the IJC relies on the 10 members of its **International Air Quality Advisory Board** to provide advice in this regard.

About the Process

The IJC establishes priorities for work on a biennial cycle in consultation with these four advisory boards and with public input. Upon adoption, the IJC assigns priorities to its boards or the council, depending on the group's mandate and expertise. Many priorities provide opportunities for collaboration between boards. Some priorities are designed for completion in two years; others are addressed for a longer term.

Recognizing the need to secure the views and opinions of basin residents, the IJC engages in a variety of public consultation activities. The information received from this broad-based consultation contributes significantly to the insight, advice and recommendations that the IJC provides to governments through its biennial reports.

Finally, no attempt was made to harmonize or consolidate the content or recommendations from the boards and council, as they represent each group's particular advice to the IJC with respect to their charge and obligations.

On behalf of the boards and council, we bring you this *2001-2003 Priorities Report*. In it you will find provocative arguments for action now to make the lakes great.

Dr. Gail Krantzberg, Director
Great Lakes Regional Office

PRIORITIES FOR 2001-2003

Priority	**Mercury**
Summary	An ecosystem approach to the health effects of mercury exposure and continued investigation of source-receptor relationships for atmospheric deposition of mercury to the Great Lakes.
Responsibility	The International Air Quality Advisory Board and Great Lakes Science Advisory Board
Product (Chapter)	1.2 - 1.3 Great Lakes Science Advisory Board 1.4 - 1.7 International Air Quality Advisory Board

Priority	**Annex 2: Remedial Action Plans and Lakewide Management Plans**
Summary	To assist the Parties in the development and implementation of Remedial Action Plans and Lakewide Management Plans through: conducting status assessments to evaluate activities, workshops to transfer information and foster implementation, and RAP and LaMP reviews in order to gauge progress toward restoration of beneficial uses.
Responsibility	Annex 2 advisory staff in collaboration with the Great Lakes Water Quality Board and Great Lakes Science Advisory Board
Product (Chapter)	2.2 - 2.4 Great Lakes Water Quality Board 2.5 Great Lakes Science Advisory Board

Priority	**Urbanization: The Land Use - Water Quality Linkage**
Summary	Renewed investigation on the impacts of land use on water quality in the Great Lakes basin with a focus on urbanization.
Responsibility	Great Lakes Science Advisory Board
Product (Chapter)	3.2 Expert Consultation on the Impact of Urban and Urbanizing Development on Great Lakes Water Quality

Priority	**Climate Change: Impacts in the Great Lakes Basin**
Summary	Investigation of the impacts of climate change on the Great Lakes basin.
Responsibility	Great Lakes Water Quality Board in collaboration with the Council of Great Lakes Research Managers
Product (Chapter)	4.2 Climate Change - Addressing Impacts in the Great Lakes Basin (Great Lakes Water Quality Board) 4.3 Climate Change – Understanding the Impact of Climate Change on Ground Water (Council of Great Lakes Research Managers)

Priority	Emerging Great Lakes Issues in the 21st Century
Summary	Investigation of the scientific dimensions of emerging issues, which includes issues that are new arrivals on the public policy agenda as well as those that are established, but changing in substance, scope or significance.
Responsibility	Great Lakes Science Advisory Board in collaboration with the Great Lakes Water Quality Board, Council of Great Lakes Research Managers and International Air Quality Advisory Board
Product (Chapter)	5.2 Expert Consultation on Emerging Issues in the Great Lakes in the 21st Century

Other Priorities and Initiatives

Summary	To identify and provide insight and advice on other topics relevant to fulfilling the purpose of the *Great Lakes Water Quality Agreement* and in accor dance with the directive to the Great Lakes Water Quality Board, Great Lakes Science Advisory board and the Council of Great Lakes Research Managers.
Product (Chapter)	6.2 Lake Erie Ecosystem Changes and Botulism Type E Outbreak 6.3 Great Lakes System Navigation Review 7.2 Health Implications of PCBs and Other Contaminants in Great Lakes Basin Waters 7.3 Great Lakes Fisheries: Retrospective and Current Concerns 7.4 Fish and Wildlife Health Effects and Exposure Study 7.5 The Agency for Toxic Substances and Disease Registry's Study of Public Health Implications of Hazardous Substances in Great Lakes U.S. Areas of Concern 7.6 Waterborne Pathogens in the Great Lakes: Existing and Emerging Needs for Assessing Risks and Solutions 9.2 Understanding Microbial Pollution and Unmonitored Chemical Contaminants in the Great Lakes Basin 9.3 Great Lakes - St. Lawrence Research Inventory 9.4 Science Vessel Coordination

RECOMMENDATIONS TO THE IJC

The following 29 recommendations were developed by the Great Lakes Water Quality Board, Great Lakes Science Advisory Board, the Council of Great Lakes Research Managers and the International Air Quality Advisory Board for the International Joint Commission's consideration. Substantiating details are provided in the sections indicated.

GREAT LAKES WATER QUALITY BOARD

The WQB recommends the following to the IJC:

6.2 LAKE ERIE ECOSYSTEM CHANGES AND BOTULISM TYPE E OUTBREAK

- Recommend that the Parties earmark adequate funding to support additional research required to characterize changes in Lake Erie and to inform program and policy decisions.

- Recommend that the two federal governments support core funding for a necessary and sufficient surveillance and monitoring program.

- Recommend that the U.S. and Canadian federal governments continue funding for investigative programs for Type E botulism that will inform policy and program decisions.

2.3 HAMILTON HARBOUR REMEDIAL ACTION PLAN CONSULTATION

- Recommend that the governments of Canada and Ontario continue to provide administrative and project support for the Hamilton Harbour Remedial Action Plan.

- Recommend that the governments of Canada and Ontario commit to a tripartite funding partnership with the city of Hamilton to finance upgrades to wastewater infrastructure.

- Recommend that the governments of Canada and Ontario commit to a funding partnership for the expeditious cleanup of contaminated sediment.

2.4 DETROIT AREA REMEDIAL ACTION PLAN CONSULTATION

- Recommend that the state of Michigan and the U.S. federal government more actively engage in the Remedial Action Plan process by providing strong and visible direction and core funding to support the Rouge River, Clinton River, and the U.S. portion of the Detroit River Remedial Action Plans in the planning and implementation of remedial programs.

- Advise the governments on the importance of engagement by the federal, state and provincial governments for all Areas of Concern in the Great Lakes basin.

- Direct the Annex 2 Task Force to explore and advise on options and alternatives for knowledge and information management and transfer.

GREAT LAKES SCIENCE ADVISORY BOARD

In developing recommendations, a primary theme emerged concerning the SAB's advisory role under the terms of the *Great Lakes Water Quality Agreement*. Simply stated, the IJC and the Parties' ability to provide sound and effective leadership is fundamentally dependent upon the existence of a policy and institutional infrastructure that nurtures and provides for science-based decision support.

Toward that end, the SAB reiterates its recommendation for a thorough and expeditious review of the *Great Lakes Water Quality Agreement* with an eye toward revisions that safeguard past progress on water quality while acknowledging and addressing new priorities, ecosystem needs, scientific advances and institutional arrangements since its last revision some 16 years ago.

The SAB recommends the following to the IJC:

1.3 CONSULTATION ON THE HEALTH EFFECTS OF MERCURY, FEBRUARY 27, 2002

- Recommend that the Parties apply powerful, large scale modeling and monitoring techniques to estimate the contribution of mercury from specific sources emitted to the atmosphere and subsequently transported and deposited into the Great Lakes. More detailed information on mercury emissions, including the chemical species of mercury is required to refine these estimates and more effectively target activities for reduction of mercury concentrations in the Great Lakes.

- Recommend that the Parties further reduce mercury emissions, including those from coal combustion, because mercury levels in fish are still above levels to fully protect human health and wildlife and because there are over 2,000 fish consumption advisories for mercury in the United States and the province of Ontario.

- Recommend that the Parties undertake prospective and retrospective epidemiological studies of high intake fish consumers and their infants in Areas of Concern and other Great Lakes area locations to better understand potential neuro-developmental effects associated with mercury and co-contaminants such as PCBs.

- Recommend that the Parties undertake investigations of sediments and nearshore soils in Areas of Concern where mercury levels in fish are elevated and where current or historical industrial sources of mercury have been identified.

3.2 EXPERT CONSULTATION ON THE IMPACT OF URBAN AND URBANIZING DEVELOPMENT ON GREAT LAKES WATER QUALITY

- Recommend that the Parties undertake a major binational investigation and research effort on the effects of urban and urbanizing development on Great Lakes water quality and develop a comprehensive response to these effects.

5.2 EXPERT CONSULTATION ON EMERGING ISSUES IN THE GREAT LAKES IN THE 21ST CENTURY

- Recommend that the Parties conduct a comprehensive review of the operation and effectiveness of the *Great Lakes Water Quality Agreement*, and seek public input, with a view to substantially revising it to reflect a current vision of water quality goals, priorities and institutional arrangements. Such a review should also consider greater accountability for implementation and for measuring progress, including a schedule of priority actions deemed essential to achieve important water quality goals.

- Recommend that the Parties develop an ecosystem forecasting capability within the auspices of a coherent binational monitoring, information and data management policy and infrastructure for the Great Lakes to inform management and decision making, and to provide for greater public accountability in reporting progress.

- Recommend that the Parties establish a binational Integrated Great Lakes Observing System as a key element of major reinvestment in Great Lakes scientific infrastructure and to provide high quality scientific information for policy decisions.

- Recommend that the Parties establish an "International Field Year for Great Lakes Research" as a special five-year program to improve the knowledge and understanding of the Great Lakes basin ecosystem.

- Ensure that the Parties:
  - provide for adequate bilateral mechanisms to identify and monitor previously undetected chemicals in the environment.
  - develop and implement strategies that use Quantitative Structure Activity Relationships to assist in the earlier identification of potential chemicals of concern.
  - increase their support of the development and validation of Quantitative Structure Activity Relationships to promote the cost effective use of chemical testing resources.
  - establish early notification processes between researchers and regulatory officials to minimize the possible injury to health and property as a result of the presence of new chemicals.

- Recommend that the Parties further develop binational institutional mechanisms to enhance bilateral cooperation and coordination for air, land and water management in order to implement a truly ecosystem approach for water quality management that involves local, state/provincial and federal governments.

COUNCIL OF GREAT LAKES RESEARCH MANAGERS

The Council recommends the following to the IJC:

4.3 CLIMATE CHANGE – UNDERSTANDING THE IMPACT OF CLIMATE CHANGE ON GROUND WATER

- Recommend to the Parties that research funding be directed to the following areas related to the impact of climate change on sources of ground water in the Great Lakes basin.

  - Examine historical data to determine how climate changes have affected ground water quality and quantity, to identify linkages between ground water and species/community distribution, to understand temporal and spatial variability and to assess how physical alterations of the land surface affect ground water recharge.
  - Improve Regional Climate Models and make them accurate for smaller scales so as to understand linkages to ground water and runoff at scales of interest.

- Maintain or increase regional and national monitoring of hydrologic information, assess aquifer extent, ground water availability and the impact of climate change on recharge and evapotranspiration.

9.2 UNDERSTANDING MICROBIAL POLLUTION AND UNMONITORED CHEMICAL CONTAMINANTS IN THE GREAT LAKES BASIN

- Recommend to the Parties that the following types of research/surveillance be conducted:
  - Determine the prevalence of selected enteric microbial pathogens, and microbial toxins, such as cyanobacterial toxins, in the Great Lakes.
  - Identify sources of microbial pathogens to waters used for human consumption or recreation, such as from ships' ballast; wastewater treatment plant effluent, storm water and agricultural feedlot runoff; boating wastes—gray and black water; and septic systems.
  - Develop testing methods and procedures for information exchange to facilitate identification of pathogens in environmental samples and enable that data to be compared with reports of disease outbreaks.
  - Study the environmental ecology of pathogens in aquatic systems to find ways to disrupt their distribution and life cycles before they can cause disease in humans.
  - Determine the significance of recreational and occupational water exposure to/in the development of gastrointestinal illness and identify risk factors.
  - Develop strategies and priorities for remediation, such as the appropriate discharge of ballast water or black and gray waters, based on identified risk factors.
  - Determine the prevalence and persistence of these pathogens before and after extreme weather events, and as a result of long-term climate change, such as lower lake levels or higher temperatures.

- Recommend to the Parties that the following types of research/surveillance be conducted:
  - Examine the output of these chemicals from wastewater and drinking water treatment plants.
  - Summarize the actual levels of these constituents detected in water supplies and compare these values to their reference or effect levels; or determine their effect levels, if unknown.
  - Determine if there are biotic indicators of the effects or presence of these chemicals.
  - Conduct experimental analyses of degradation times for these chemicals under natural conditions.
  - Determine if wastewater or drinking water treatment processes can be changed to reduce or remove these chemicals.

9.3 GREAT LAKES - ST. LAWRENCE RESEARCH INVENTORY

- Recommend to the Parties that organizations granting funds for Great Lakes research be encouraged to routinely utilize the Great Lakes – St. Lawrence Research Inventory as a tool to identify gaps in current Great Lakes research and that researchers/managers be provided with incentives to participate.

9.4 SCIENCE VESSEL COORDINATION

- The International Joint Commission continue its strong support for annual science vessel coordination workshops.

1.6 MODELING OF ATMOSPHERIC MERCURY TRANSPORT AND DEPOSITION TO THE GREAT LAKES BASIN USING THE NOAA-HYSPLIT MODEL

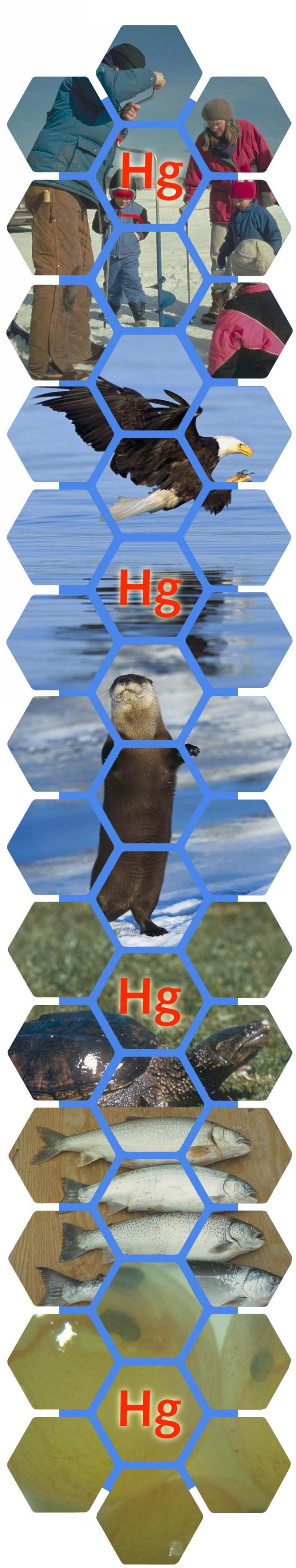
The IAQAB recommends the following to the IJC:

- Every effort should be made to increase the detail, particularly on speciation of mercury, and accuracy associated with emissions inventories in the United States, Canada, and on a global basis. Some coordination in the production of inventories between the United States and Canada, resulting in largely seamless inventories applicable to the same base year, would be most helpful.

- Additional detailed ambient monitoring activities, including the completion of enhancements to the recently established mercury measurement capabilities of the Integrated Atmospheric Deposition Network, should be supported, and provisions should be put in place to make all completed measurements available in a timely fashion.

- A mercury modeling intercomparison study in North America, similar to that currently underway in Europe, could stimulate improvements while increasing confidence in the outcomes and linkages developed by atmospheric transport models. Improvements to the emissions data base and assembly of a comprehensive ambient measurement data set should be part of this model intercomparison.

- Following model intercomparison and comparison against measured data, these models should be used as a predictive tool in determining the potential impact on deposition of proposed mercury emission control programs currently under consideration in the United States and Canada.



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MERCURY

CHAPTER ONE Mercury

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The assistance of Roch Duval and Rachelle Laurin, Ontario Ministry of the Environment's Environmental Monitoring and Reporting Branch, in the preparation of several maps in this chapter, is gratefully acknowledged.

1.1 HEALTH EFFECTS OF MERCURY IN THE GREAT LAKES BASIN: INTRODUCTION

The health effects of mercury have been a continuing concern of the Great Lakes Science Advisory Board (SAB). Numerous anthropogenic sources of mercury add to natural levels and can be found at the local, regional and global levels. Having entered the environment, mercury cycles repeatedly within the biosphere and, in water, can be converted to methylmercury and biomagnify to toxic levels as it moves up the food chain. Adverse health effects are documented, among others, via fish consumption where subtle, adverse neurological health impacts can be measured at low doses. Mercury remains a significant health concern, as evidenced by fish consumption advisories throughout the Great Lakes states and Ontario.

More detailed evaluations of source inputs and mercury speciation are needed to better understand mercury contributions and more effectively target mercury reduction activities, particularly from air sources. Mercury levels in fish are still above levels to fully protect human health and wildlife requiring further efforts to control mercury inputs and loadings, including those from coal combustion. The over 2,000 fish consumption advisories for mercury throughout the United States and the province of Ontario, provide overwhelming evidence regarding the need to reduce mercury emissions. Prospective and retrospective epidemiological studies should be undertaken of high intake fish consumers and their infants in Areas of Concern and other Great Lakes area locations to better understand potential neurodevelopmental effects associated with mercury and co-contaminants such as PCBs.

The over 2,000 fish consumption advisories for mercury throughout the United States and the province of Ontario, provide overwhelming evidence regarding the need to reduce mercury emissions.

In 1998, Health Canada's Great Lakes Health Effects Program compiled data and statistics on mortality, morbidity and congenital abnormalities that might be linked to pollution in Areas of Concern. Cerebral palsy had been included because of the association with the population exposures to methylmercury both at Minamata, Japan in the 1950s and in the Iraq population in the 1960s and 1970s. These Health Canada reports indicated that there were statistically significant increases in hospitalization rates for cerebral palsy in certain Areas of Concern compared with the rest of the province of Ontario. Several of these Areas of Concern also had a history of large industrial uses of mercury, particularly for manufacturing chlorine and sodium hydroxide.

Mercury (Hg) is a heavy metal and naturally occurring element that has been mobilized by anthropogenic activities and contaminated the environment. Many activities lead to this global pollution, including the burning of municipal trash, burning of high sulfur coal containing cinnabar (HgS) in coal-fired power plants, smelting, chloralkali plants, and gold extraction, as well as from historical uses of fungicides containing mercury, latex paints, and in the pulp and paper industry. Atmospheric concentrations peaked in the 1960s–1970s, and have been declining since then (Engstrom and Swain, 1997). It has been estimated that human activities contribute 70-80 percent of the total annual mercury to the atmosphere (Fitzgerald 1995) and that greater than 95 percent of the atmospheric mercury in the vapor phase exists as elemental mercury. There is a very dynamic redox cycle and exchange between the oceans and atmosphere (Mason and Sullivan, 1997). The remaining balance of the mercury exists as oxidized reactive gaseous mercury, particulate complexes of divalent mercury, and as monomethylmercury (MMHg) (Stratton and Lindberg, 1995a;1995b). The total mass of mercury in the atmosphere has been estimated to be between 5000-6000 metric tonnes (Fitzgerald and Watras, 1989) with approximately half due to anthropogenic sources (Lindqvist *et al.*,1991).

The total mass of mercury in the atmosphere has been estimated to be between 5000-6000 metric tonnes (Fitzgerald and Watras, 1989) with approximately half due to anthropogenic sources (Lindqvist *et al.*,1991).

Mercury in its elemental state has low reactivity and a long atmospheric residence time, thus allowing it to be mixed in the atmosphere on a global scale. Reactive gaseous mercury is very soluble in water and thus is effectively scavenged by wet deposition (Fogg and Fitzgerald, 1979; Mason *et al.*, 1994). Particulate forms are removed by dry deposition (Keeler *et al.*,1995). Once removed from the atmosphere, much of the deposited mercury ends up in aquatic systems due to direct deposition and transfer from the terrestrial ecosystem to aquatic ones (Mierle and Ingram, 1991). Mercury effects on fish, birds and mammals that eat contaminated fish are of significant concern (Wiener *et al.*, 2003). Our public health and wildlife concerns about mercury stem from exposure to the methylated form, MMHg. In anaerobic environments, such as lake sediments, mercury is transformed to MMHg by microbial action, most notably by sulfur reducing bacteria. The MMHg diffuses into the water column where it can be taken up by fish, accumulating in their muscle tissue by binding to thiol groups. MMHg is the most toxic form of mercury and causes neurological, liver and kidney damage, as well as neurodevelopmental effects in children (Davidson *et al.*, 2000; Grandjean *et al.*, 1997; NRC 2000). Reproductive effects also have been documented in fish and fish-eating wildlife (Hammerschmidt *et al.*, 2002; Scheuhammer 1991). In the United States, 45 states advise the public against unlimited consumption of freshwater fish due to their MMHg levels. In addition, the U.S. FDA has issued a mercury-based national fish consumption advisory for five species of commercial oceanic fish. The U.S. EPA considers an acceptable dose of mercury to be 0.1 μg/kg body weight/day, and this was recently supported by an independent study of the National Academy of Sciences (NRC 2000).

1.3.1 Background

The IJC chose the issue of mercury in the Great Lakes basin as one of its priorities for the 2001-2003 priorities cycle and the SAB's Workgroup on Ecosystem Health prepared the following workplan:

"With advances in toxicology and epidemiology there has been a reevaluation of the risks associated with exposures to mercury. There are concerns that levels in the Great Lakes remain high enough to cause developmental effects in infants. Mercury is one of the persistent toxic substances that has been of interest to the International Joint Commission under the *Great Lakes Water Quality Agreement* for a long time and there is a need, in concert with other parts of the organization, to provide the IJC with advice on the current situation."

Based on this workplan, the Workgroup on Ecosystem Health undertook a Consultation on the Health Effects of Mercury, at the February 27, 2002 meeting of the Workgroup on Ecosystem Health. Facts concerning cerebral palsy causation and association with methylmercury poisonings in Minamata and Iraq were discussed as were other neurological impacts caused by mercury exposure (NRC 2000; ATSDR 1999). The participants discussed the various limitations of the approach that had been used by Health Canada under the headings of data issues (e.g. repeated hospitalization of cases), statistical issues and issues concerning alternative etiological factors. This consultation concluded with a consensus that more research was needed in order to draw any firm conclusions between a possible relationship of cerebral palsy cases in Canadian Areas of Concern and exposure to mercury.

To obtain the most recent information on mercury toxicity, the SAB then organized a conference on mercury pollution and human health in the Great Lakes basin, held in Windsor, Ontario, February 26-27, 2003. Presenters at the conference included leading mercury experts in the world. The conference was designed to address multimedia sources and sinks, exposures of critical subpopulations, effects, and remedial options and was undertaken in collaboration with the IAQAB and the Health Professionals Task Force, using an ecosystem approach.

A group of seven health scientists, two on the SAB and five outside the SAB, were charged with listening to the conference findings and coming up with a Consensus Statement. The major conclusions in the Consensus Statement were developed and presented at the conference, seeking and receiving input from speakers and participants. Following the conference, the Consensus Statement was reviewed by U.S. EPA Region 5 scientists involved in mercury reduction activities as part of the binational toxics strategy. The following is the consensus statement.

1.3.2 Consensus Statement from the International Joint Commission Workshop

Mercury Sources and Sinks

There are numerous anthropogenic sources of mercury to the Great Lakes area environment from local, regional and global sources (U.S. EPA 1997a). Anthropogenic sources increase mercury levels above those resulting from natural sources. Once entering the environment, mercury will cycle repeatedly within the biosphere, between earth, air, and water. In sediments, it can be converted to methylmercury and biomagnify up the food chain to toxic levels (U.S. EPA 1997a; NRC 2000). Mercury is of no biological value.

More detailed evaluations of source inputs and mercury speciation, particularly from air sources, will help to better understand mercury contributions and more effectively target mercury reduction activities. Nevertheless, there are powerful techniques based upon a combination of modeling and monitoring that can be used to estimate mercury source contribution to aquatic receptors (Cohen 2001).

Using these techniques, coal combustion appears to be the largest, unregulated source of mercury air deposition to the Great Lakes area (Cohen 2001). Approximately 20 percent of mercury loadings to the Great Lakes region are from global sources outside the United States and Canada, although more information is needed on global mercury emissions to reduce uncertainty in loading estimates (Dastoor 2003; Cohen 2001). Therefore, international cooperation, as in the successful control and phase-out of harmful chloroflurocarbons, will be required to protect water resources in the Great Lakes area.

Past practices and former industrial sites, such as mercury cell chlor-alkali plants, may also contribute mercury contamination to the Great Lakes watershed, but these quantities and pathways are poorly understood at this time (Trip and Thorleifson, 1998). Historical farming and recreational lands pesticide applications were a significant source of mercury input into the environment. The long-term fate of mercury from these practices is not well understood and should be quantified with respect to groundwater, soil and atmospheric re-emissions.

While mass balance approaches and additional science will help elucidate mercury sources, loadings, and fate, continued steps can be taken now at the local and regional level to reduce mercury in products and waste streams. Lowering mercury releases is good public health policy.

... steps can be taken now at the local and regional level to reduce mercury in products and waste streams. Lowering mercury releases is good public health policy.

Mercury Exposure and Human Health Effects

Adverse health effects resulting from mercury exposure via fish consumption have been seen in several locations around the world (NRC 2000; ATSDR 1999). Mercury causes subtle, adverse neurological health impacts at very low doses (NRC 2000; ATSDR 1999). Recent studies suggest that mercury may be associated with increased risk of myocardial infarction in men (Guallar et al., 2002; Yoskizawa et al., 2002). Mercury exhibits characteristics similar to lead toxicity and as more information is discovered regarding mercury toxicity, the exposure level at which mercury causes adverse health effects has been lowered (NRC 2000).

Current mercury exposures in some high intake fish consumers in the Great Lakes region are above blood levels (5.8 ppb, from U.S. EPA's Reference Dose) of potential health concern (Cole 2003). In several other locations outside North America, children born of women having elevated levels of mercury in blood or hair from fish consumption have been found to have a range of neurological and neuropsychological deficits, as shown in the National Research Council's (National Academy of Sciences) evaluation (NRC 2000). The NRC reached the following conclusions:

> "*. . . individuals with high methylmercury exposure from frequent fish consumption might have little or no margin of safety (i.e. exposures of high-end fish consumers are close to those with observable effects). The population at highest risk is the children of women who consumed large amounts of fish and seafood during pregnancy. The committee concludes that the risks to that population is likely to be sufficient to result in an increase in the number of children who have to struggle to keep up in school and who might require remedial classes or special education.*"

Based upon findings presented at the mercury workshop and conclusions from the NRC evaluation, some high-intake Great Lakes area women fish consumers would be expected to have mercury exposures resulting in adverse health effects to children.

Mercury Levels in Great Lakes Region Biota

Mercury is still a significant health concern for human fish consumers and wildlife. In the United States a total of 2,242 fish advisories exist for mercury, dominating all other chemical based fish advisories (U.S. EPA 2001a). Due to widespread mercury contamination of sportfish, all Great Lakes states and the province of Ontario have general fish consumption advisories covering all inland waters (U.S. EPA 2002a; Ontario Ministry of the Environment 2002). Women of child bearing age and children under 15 are advised not to consume more than a meal per week (or four meals per month) of sportfish. National advisories have also been issued by U.S. EPA regarding sport fish consumption and by the U.S. FDA on commercial fish consumption (U.S. EPA 2001a, b; U.S. FDA 2001).

While mercury levels in Great Lakes fish have declined due to regulation of point sources of mercury, some Areas of Concern, such as the St. Clair River, Detroit River/Lake St Clair, Torch Lake and Deer Lake, still have sport fish with mercury considerably above acceptable values to protect human health (MDEQ 2003; MDCH 2002; Weis 2003). Mercury levels below 0.1 ppm are needed to protect high intake fish consumers, using U.S. EPA's recent Reference Dose for mercury (U.S. EPA 2001a). Mercury in larger size predator sport fish, such as walleye, can exceed 1 ppm in some Areas of Concern (MDEQ 2003; Day 2003). Investigations of sediments and near shore soils should be undertaken in Areas of Concern where mercury levels in fish are elevated and where current or historical industrial sources of mercury have been found.

Outside the Great Lakes, mercury is a problem for inland lakes, especially those where methylation of mercury is favored (Weiner 2002). Water acidity increases mercury methylation and bioavailability (NRC 2000; Weiner 2002). Nitrogen and sulfur oxides loadings into inland lakes may

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be important contributors to lake acidification. Deforestation, wetlands, watershed size, and fishing pressures also influence the amount of mercury in fish (Lucotte 2003). Combustion sources and atmospheric loadings likely dominate mercury inputs to the majority of inland lakes (U.S. EPA 1997a).

Wildlife also are affected by mercury. Reproductive impairment has been shown to occur in loons from Minnesota lakes, Eastern Canada and Ontario where fish mercury levels are above 0.4 ppm (Barr 1986; Meyer *et al.*, 1998; Kenow 2003; Weiner 2002).

Information on mercury trends in the environment is very limited, as data have not been collected for the purpose of assessing trends. Great Lakes fish such as smelt have shown gradual declines and sediments in open Great Lakes waters also show decreasing levels of mercury (U.S. EPA 2003a). This is good news, but such data should not be viewed with complacency. Without pollution controls, increases in fossil fuel combustion, particularly coal, around the world will increase atmospheric releases of mercury with potential impacts on the Great Lakes area. Trends of mercury in fish and sediments from small inland lakes may be important sentinels and serve as an early warning for future mercury problems in the Great Lakes.

As the mercury levels in fish are still above levels to fully protect human health and wildlife, further efforts to control mercury inputs and loadings must be undertaken. Based on the high nutritional value of fish, lowering mercury burdens in fish will be intrinsically healthful for all who consume fish.

Future Health Research

Surveys of high-intake North America fish consumers with elevated mercury exposures should be undertaken. Valuable epidemiological information could be obtained on similarities and differences between other mercury health studies as well as the effects of co-contaminants such as PCBs and selenium. Only one major study has evaluated the health effects caused by exposure to both PCBs and mercury (Grandjean *et al.*, 1997). The range of U.S. EPA's Reference Dose and the Agency for Toxic Substances and Disease Registry's Minimal Risk Level for chronic oral mercury exposure reflects the uncertainty regarding the other contaminants observed with mercury.

More information is needed on how the sources of mercury tie into human exposure and health effects. Gathering information on health effects of mercury from infancy through old age would be of value.

In establishing environmental health research protocols, there should be coordination between health researchers in the North American community, including those doing Arctic research. Health data in governmental repositories should be evaluated to determine if it can be better organized to permit the extraction of data.

To better understand potential neurological associations and other health effects resulting from mercury exposures in high intake fish consumers, including those living near Areas of Concern where mercury levels in fish are elevated, prospective information is needed on mercury in maternal hair and cord blood at the time of birth. Followup studies on infants and children would determine if cause-effect relationships with mercury exposure are occurring now. While retrospective studies of cerebral palsy cases in Canadian Areas of Concern may be difficult and not yield definitive information, it would be useful to further evaluate if a causal relationship with mercury exposure exists. Further consultation with experts in mercury epidemiology is warranted.

Integration of Risk Assessment, Risk Management and Risk Communication

Mercury fish consumption advisories, for some Areas of Concern and inland waters within the states and Canadian provinces, will exist for several decades. New and creative risk communication measures should be developed to reduce mercury exposure resulting from sportfish and commercial fish consumption. Recent advisories issued by Ontario and the Great Lakes states consider both sportfish and commercial fish consumption (WDH/WDNR 2002; Ontario Ministry of the Environment 2002).

There is great variation in mercury methylation between lakes. Those lakes that have fish and wildlife species that are at high risk or low risk should be identified.

Risk management and risk communication decisions, which logically follow risk assessment findings, should consider the health benefits from eating fish and wildlife and the adverse health effects that could result from attempts to limit consumption or to significantly alter consumption patterns. The potential consequences of advice to limit consumption may have negative implications not only in terms of nutrition, but may also contribute to socio-economic, cultural and life style disruption and these can have additional adverse effects on health. Realities of subsistence living, particularly among the aboriginal populations should be brought into the risk management equation. Communication approaches that are sensitive to cultural and socio-economic concerns, need to be developed in consultation with First Nations. The benefits of fish consumption should also be communicated, placing emphasis on those fish that have the most benefit (e.g. Omega-3 fatty acids) and lowest levels of toxicants.

Consensus Recommendations

The following Consensus Recommendations were formulated by the Mercury Consensus Workgroup and are endorsed by the Science Advisory Board.

The SAB recommends the following to the IJC.

- **Recommend that the Parties apply powerful, large scale modeling and monitoring techniques to estimate the contribution of mercury from specific sources emitted to the atmosphere and subsequently transported and deposited into the Great Lakes. More detailed information on mercury emissions, including the chemical species of mercury is required to refine these estimates and more effectively target activities for reduction of mercury concentrations in the Great Lakes.**

- **Recommend that the Parties further reduce mercury emissions, including those from coal combustion, because mercury levels in fish are still above levels to fully protect human health and wildlife and because there are over 2,000 fish consumption advisories for mercury in the United States and the province of Ontario.**

- **Recommend that the Parties undertake prospective and retrospective epidemiological studies of high intake fish consumers and their infants in Areas of Concern and other Great Lakes area locations to better understand potential neurodevelopmental effects associated with mercury and co-contaminants such as PCBs.**

- **Recommend that the Parties undertake investigations of sediments and nearshore soils in Areas of Concern where mercury levels in fish are elevated and where current or historical industrial sources of mercury have been identified.**

1.3.3 Mercury Consensus Workgroup

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1.4 INTRODUCTION: THE INTERNATIONAL JOINT COMMISSION AND ATMOSPHERIC DEPOSITION

1.4.1 Background

The International Joint Commission (IJC) has a longstanding interest in the transport and deposition of persistent toxic substances to the Great Lakes basin via the atmosphere. Early in the 1980s, working with the IJC's Great Lakes Water Quality Board, in one of the first estimates of its type, Dr. Steve Eisenreich and Dr. William Strachan determined that approximately 90 percent of the loading of PCBs to Lake Superior could be attributed to deposition from the atmosphere. A similar, albeit smaller portion of this loading to the other Great Lakes was estimated to also arise from this pathway.

In their 1985 report, the Water Quality Board tabled the list of 11 Critical Pollutants; and for each there was reason to believe or evidence to support the fact that the atmosphere would prove to be a significant pathway. Following that report, three of the IJC's advisory boards – Great Lakes Water Quality Board, Great Lakes Science Advisory Board and the International Air Quality Advisory Board (IAQAB) – began the production of the first binational summary of emissions estimates for the 11 Critical Pollutants. The IAQAB also developed a map of the atmospheric region of influence, indicating such regions on the basis of emission travel time (one day, three day, five day) to the lakes. These and other developments contributed to the inclusion of Annex 15: Airborne Toxic Substances in the 1987 Protocol to the *Great Lakes Water Quality Agreement.*

TABLE 1
Critical Pollutants Identified by the Water Quality Board

Total polychlorinated biphenyls (PCBs)
DDT and metabolites
Dieldrin
Toxaphene
2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD)
2,3,7,8-tetrachlorodibenzofuran (2,3,7,8-TCDF)
Mirex
Mercury
Alkylated lead
Benzo(a)pyrene
Hexachlorobenzene

Source: IJC-GLWQB, 1985

TABLE 2
Estimates of the Percent of Great Lakes Loadings Attributable to the Atmospheric Deposition Pathway

Pollutant	Lake Superior	Lake Michigan	Lake Huron	Lake Erie	Lake Ontario
DDT	97[a]	98[a]	97[a]	22[a]	31[a]
Lead	97[a] ; 64[b] ; 69[d]	99[a]	98[a]	46[a]	73[a]
Mercury	73[d]	> 80[j]	[k]	[k]	[k]
PCBs	90[a]; ~ 95[b,c]; 82[d]	58[a]	78[a]	13[a]	7[a]
PCDD/F	~ 100[c] ~ 80[f]	50-100[f] (PCDD) 5-35[e] (PCDF) 88[f]	86[f]	~ 40[f]	5-35(PCDD)[e] < 5 (PCDF)[e]
Benzo(a)pyrene	96[a]	86[a]	80[a]	79[a]	72[a]
Hexachlorobezene	99[f]	95[f]	96[f]	> 17[f]	40[f]
Mirex	[k]	[k]	[k]	[k]	~ 5[a]

References and Notes: (a) Strachan and Eisenreich (1988), percentages of total inputs; (b) Hoff *et al.,* (1996); (c) Net loss of PCBs to the atmosphere of 1600 kg/year, total non-atmospheric inputs of approximately 70 kg/year; (d) Dolan *et al.,* (1993); (e) Pearson *et al.,* (1998); (f) Cohen *et al.,* (1995); (J) Mason and Sullivan (1997); (k) no estimates could be found

1.4.2 Annex 15 to the Great Lakes Water Quality Agreement (1987)

Annex 15, added to the Agreement in 1987, committed the governments of the United States and Canada (the Parties) to conduct research, surveillance and monitoring, and implement pollution control measures to reduce atmospheric deposition of toxic substances, particularly persistent toxic substances, to the Great Lakes basin ecosystem.

Research was to focus on the determination of pathways, fate and effects of such toxic substances, including an understanding of the processes of wet and dry deposition and vapor exchange of toxic substances; the effects of persistent toxic substances, taken singly or synergistically; and the development of models to determine: the significance of atmospheric loadings to the Great Lakes system relative to other pathways, and the sources of such substances from outside the Great Lakes system.

The federal, state and provincial governments also agreed to develop and adopt programs and measures for the elimination of discharges of persistent toxic substances.

The establishment, by the governments of the United States and Canada, of an Integrated Atmospheric Deposition Network (IADN) to attempt to quantify the total and net atmospheric input of these toxic substances to the Great Lakes system and define the temporal and spatial trends in the atmospheric deposition was among the responses to Annex 15.

1.4.3 Significant Activities Since 1987 Under Annex 15

In 1989 the IAQAB compiled a first inventory of atmospheric sources of the Critical Pollutants (L. Smith and E. Voldner, "Production, Usage and Atmospheric Emissions of 14 Priority Toxic Chemicals"). This report concluded that "a larger undertaking of further research on toxic chemicals emissions will be required to provide the necessary information on atmospheric emissions and their subsequent deposition in the Great Lakes region." Notwithstanding some observed progress in emission inventory activities, identical summary remarks could be and have been made today, over a decade later, with regard to the Level I (largely the current contaminants considered in the Smith/Voldner report) and Level II contaminants on the current Binational Toxics Strategy list.

Shortly thereafter, in reviewing several first efforts at modeling the transport and deposition of persistent toxic substances, the IAQAB noted that the quality of these

modeled deposition estimates would be very dependent on the quality of emission inventories, on knowledge of the chemical and physical processes affecting their lifetimes in the atmosphere and on support for further model development.

In October 1993, the IAQAB report *Progress by the Parties in Completing an Inventory of Toxic Air Emissions and in Assessing Toxic Air Deposition in the Lake Superior Basin* concluded that, within that basin, the emission inventories of the time were inadequate and as a result, further development of deposition models was not warranted.

Subsequently, under the Modeling element of the Annex, in the IJC's *Seventh Biennial Report on Great Lakes Water Quality* (December 1993), the Commission noted that a focus on research to improve understanding of the pathways, fate and effects of airborne toxic substances, as required by Annex 15, has not occurred. Specifically a research program emphasizing atmospheric processes, transfer coefficients, and gas exchange processes would be needed. The Lake Michigan Mass Balance Study and other initiatives ultimately would respond in part to this need, but important coordinated binational research remains to be conducted.

The *Seventh Biennial Report on Great Lakes Water Quality* also recommended "federal governments provide co-ordinated national inventories of toxic air emissions...A *binational* (emphasis added) group should be established to review, co-ordinate and propose means to (a) identify data requirements (b) develop guidelines and timetables; (c) set priorities; and (d) propose and co-ordinate research." Subsequent to this recommendation, in what could be construed as a regional response, the Great Lakes Air Toxics Emission Inventory was established; however, the need for a binational inventory characterizing sources from outside the basin that contribute significantly to Great Lakes deposition went largely unaddressed at the bilateral level. Also, in April 1996, the IAQAB expressed its concerns regarding the deregulation of the electrical utilities industry in the United States. Specific to persistent toxic substances, the IAQAB stated that an increase in mercury emissions as a result of deregulation would be contrary to the commitment to virtual elimination made by the governments of the United States and Canada in the *Great Lakes Water Quality Agreement*. The IAQAB would further consider this source sector among others in its mercury transport modeling work, described later in this report.

In the IJC's *Eighth Biennial Report on Great Lakes Water Quality* (June 1996), the IJC noted that, given the progress made in reducing effluent inputs of persistent toxics to the Great Lakes basin, the air pathway was increasing in significance. The United States Toxic Release Inventory and Canadian National Pollution Release Inventory emissions data were cited in support of this observation. The IJC extended the scale of its interest to "encompass most of North America, and, for some purposes, the globe."

1.4.4 The HYSPLIT Modeling of Dr. Mark Cohen

In March 1995, the Great Lakes Science Advisory Board's Work Group on Parties Implementation was among the first to review the Commoner/Cohen report "Quantitative Estimation of the Entry of Dioxins, Furans and Hexachlorobenzene into the Great Lakes from Airborne and Waterborne Sources" (Cohen *et al.,* 1996). Responding directly to one of the elements of Annex 15, this report was a first attempt to model the atmospheric deposition of dioxin and related compounds to the lakes from sources and source categories throughout the United States and Canada.

During that year, the IJC also invited the IAQAB to become directly involved with the Agreement Boards (Great Lakes Water Quality Board, Great Lakes Science Advisory Board and Council of Great Lakes Research Managers) in the establishment and execution of the IJC biennial Great Lakes priorities.

In subsequent months, as a priority activity, the IAQAB asked Dr. Cohen to report on the adequacy of available data, information and programs in four areas vital for successful modeling of atmospheric transport and deposition:

- physical and chemical properties of the Binational Toxics Strategy Level 1 contaminants (Critical Pollutants);
- emission inventories for these contaminants;
- availability of models capable of estimating atmospheric transport and deposition; and
- adequacy of ambient monitoring information for comparison to model determinations.

Dr. Cohen's work confirmed that the Binational Toxics Strategy Level 1 contaminants and Critical Pollutants would be subject to atmospheric transport and deposition. However, the incomplete knowledge of physical and chemical properties, the poor or unknown quality and breadth of emissions inventories in the United States and Canada, the paucity of support for efforts to model transport and deposition, and the absence of some of the Critical Pollutants from ambient monitoring programs all severely limited the number of contaminants whose transport and deposition might be modeled successfully. Dr. Cohen determined that modeling could only be attempted for three of the Binational Toxics Strategy Level 1 contaminants — dioxin, cadmium and mercury.

The IAQAB subsequently engaged Dr. Cohen to further refine his earlier application of the NOAA-HYSPLIT model to the transport and deposition of dioxin into the Great Lakes basin. The outcome of this work can be found in the IJC's *1997-1999 Priorities and Progress under the Great Lakes Water Quality Agreement* and further described as part of the 1999-2001 *Priorities and Progress under the Great Lakes Water Quality Agreement*. The model output demonstrated that dioxin transported via the atmosphere from distant sources is a significant portion of the total loading to the lakes, particularly Lake Superior, and allowed identification of the most significant known source sectors. Figure 1 is one of many illustrations of the contribution of local and distant dioxin sources to deposition in Lake Superior. Much more detail on this modeling process is available in the 1997-99 report and a recent publication (Cohen *et al.,* 2002).

In its *Tenth Biennial Report on Great Lakes Water Quality* (July 2000), the IJC encouraged further identification of in-basin and out-of-basin sources whose emissions of persistent toxic substances are deposited in the lakes via atmospheric transport. It also advocated the addition of dioxin and mercury to the suite of contaminants measured by Integrated Atmospheric Deposition Network ambient monitoring sites in the Great Lakes basin.

1.4.5 The IAQAB and the 1999-2001 *Priorities and Progress under the Great Lakes Water Quality Agreement*

The IAQAB portion of the *1999-2001 Priorities and Progress under the Great Lakes Water Quality Agreement* contains a further refinement of the estimate of the impact of distant sources of dioxin on the lakes. Included was a delineation of the form of that impact (wet and dry deposition) as well as a comparison of the model estimates to a limited number of available ambient dioxin measurements. The IAQAB recommended further improvements in the emission inventories for this contaminant, particularly within the Great Lakes Air Toxics Emission Inventory, and inclusion of estimates of emissions arising from backyard refuse burning.

The IAQAB sponsored two cooperative workshops that examined various models and methodologies for the determination of atmospheric transport and loading of selected persistent toxic substances to various important watersheds. As one outcome, the IAQAB concluded that, if good quality data on the physical and chemical properties of the contaminant and emissions are available, along with ambient data for verification, current models can estimate the input of several persistent toxic substances to the Great Lakes basin. Adequate emissions inventories are crucial to any modeling effort, and the quality of these should be determined as a first step in considering any modeling activity.

Further, model outputs can be indicative of the approximate significance of various source sectors, and large individual sources. An examination of current and historic land use records and the use of pesticide volatilization models to better qualify deposition of banned pesticides were also noted as approaches worthy of further consideration.

The plume associated with large urban centers was shown to contain significant concentrations of some persistent toxic substances, such as PCBs. For example, the plume from Chicago, particularly in the summer months, includes substantial amounts of this contaminant; these amounts are greatly in excess of the total from known point sources in the region. Recent estimates suggest that the amount in question is in hundreds of kilograms per year as compared to a sum total of approximately 30 kg/yr estimated as emitted from the point sources.

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Recommended actions included further effort to characterize areal sources such as landfills, wastewater sludge drying operations and transformer storage yards in urban settings around the basin and their subsequent incorporation as sources into models.

The IAQAB expressed concern that the Integrated Atmospheric Deposition Network master station at Sleeping Bear Dunes, Michigan due to its relatively remote location on the eastern shore of Lake Michigan, appears to underestimate the concentrations of PCBs and other contaminants prevailing over the lake. The extent of this underestimation should be determined by over-lake sampling and the application of models. The completion of the Lake Michigan Mass Balance Study for all pathways for PCBs, mercury, trans-nonachlor and atrazine and the extension of this approach to other persistent toxic contaminants also were encouraged.

The IJC, in its *Eleventh Biennial Report on Great Lakes Water Quality*, amplified the recommended needed improvements in emissions inventories and the extension of monitoring activities to better estimate urban plumes and other inputs.

1.5 THE INTERNATIONAL AIR QUALITY ADVISORY BOARD MERCURY TASK FORCE / COMMISSION ON ENVIRONMENTAL COOPERATION WORKSHOP ON ATMOSPHERIC MERCURY: SCIENCE AND POLICY – RESEARCH TRIANGLE PARK, NORTH CAROLINA, DECEMBER 200

1.5.1 Introduction

The IAQAB and the Mercury Task Force of the Sound Management of Chemicals of the Commission for Environmental Cooperation co-sponsored two workshops on mercury over the last several years. The first, *The State of Scientific Knowledge Related to Mercury,* held in Las Vegas, Nevada in October 1998, brought together scientists from the United States, Canada and Mexico to explore emissions, ambient air, and deposition information for the various forms of mercury as well as related impacts on human and ecosystem health. Enhancement of source and ecosystem measurements of mercury and improvements to available atmospheric models were recommended, along with more effective communication between the scientific community and policy makers in planning and achieving further reductions in anthropogenic emissions.

To address these needs, prominent scientists and policy makers from the United States, Canada and Mexico met in Research Triangle Park, North Carolina in December 2001 at a second joint workshop, *Addressing Atmospheric Mercury: Science and Policy*.

Estimates of worldwide mercury emissions as well as those of the three countries were reviewed, along with continental monitoring activities, including determination of wet deposition, concentrations in ambient air, and related estimates of dry deposition. The use of these data in global, continental and regional atmospheric mercury transport models was examined. The need for a rigorous characterization of natural sources of mercury was emphasized.

Participants recognized the minor but significant global anthropogenic contribution to mercury loading in North America and re-emphasized the need for further routine and specialized studies of sources, ambient air concentrations, and related wet and dry deposition determinations.
In assessing the outcome of the meeting, the IAQAB and the Mercury Task Force of the Sound Management of Chemicals of the Commission on Environmental Cooperation made observations and recommendations in several areas.

1.5.2 Sources

While significant fluctuations in the global emissions inventories for mercury were not apparent in recent years, changes were observed in their dominant sources and geographic locations.

The global inventory work of Pacyna & Pacyna (Figure 2) suggests no significant change in the estimated 2000 tonnes per year total global annual release of mercury from anthropogenic sources to the atmosphere between 1990 and 1995. In the 1995 version, North American and European sources showed decreasing emissions while the Asian contribution has increased by over 25 percent, apparently due largely to increased coal combustion in China.

While there is a distinct albeit imprecise contribution from natural sources, **anthropogenic sources will continue to account for the most substantial portion of total emissions, and, reduction of mercury emissions from anthropogenic sources should continue to be aggressively pursued.**

Emission inventories, particularly in the breadth and the quality assurance of data collected, appear to lack scope, rigor and transparency.

1.5.3 Transport and Deposition

It is apparent that further research is needed to better understand the complex atmospheric kinetics and chemistry of mercury, the interaction with other pollutants and species, and the subsequent impact on transport and deposition processes.

A mass balance / whole-ecosystem approach is necessary to track the sources and movement of mercury throughout the ecosystem, including its entry into and further concentration within the food chain.

1.5.4 Monitoring

Establishment of core monitoring sites, with measurement of all relevant chemical species in all relevant phases, thorough spatial coverage, further standardization in sampling and analytical protocols and in the selection and application of meteorological data and an enhancement in overall quality assurance and control are all necessary activities. Enhanced and

sustained monitoring of the parameters necessary to estimate dry deposition is essential for a complete understanding of mercury loading in the environment. Near-source monitoring is necessary to achieve a better understanding of emitted plume chemistry. Increased spatial and temporal coverage in monitoring activities, especially in and over water and downwind of urban areas, was identified as a need.

Determination of the mercury levels in freshwater fish should be sustained and consideration should be given to more extensive monitoring of marine fish and other seafood.

1.5.5 Modeling

The global contribution to domestic mercury pools must be further considered in the development of continental and large regional scale models. Comparison of models and their outputs should continue.

1.5.6 Policy

The impact of mercury on human health will continue to be the most effective stimulus for appropriate control initiatives for mercury emissions locally, regionally and globally.

Policy makers must function in a context of uncertainty and scientists should consistently attempt to narrow this uncertainty and, to the extent possible, reach some "precautionary approach" consensus prior to discussions with their policy counterparts.

Mercury emission inventories (anthropogenic and natural), global contributions, and wet and dry deposition mechanisms, have been identified as among the many issues that need better determination and characterization. The unknowns surrounding these issues could hinder further policy efforts. Some level of consensus on how best to manage these unknowns among the scientific community would be most helpful to policy development.

Regular dialogue between the scientific and policy elements within environmental agencies was seen as crucial to scientific work and the design of relevant and responsive policy.

1.5.7 Recommendations from the Workshop

A continued focus be maintained in the three countries, United States, Canada and Mexico, on further reductions in emissions of mercury from anthropogenic sources through an effective combination of voluntary and regulatory programs.

A long-term commitment should be made to the improvement of the quality, comparability and scope of mercury source and ambient measurements, including levels in selected biota, the availability of appropriate meteorological data, and to support the associated modeling efforts.

Canadian and American programs to measure the mercury content in freshwater fish consumed by humans should be continued and current measurements among marine food species should be enhanced. Mexico should be supported in the initiation and maintenance of such programs.

The modeling community should develop a comprehensive list of mercury measurement needs central to the evaluation and further improvement of models, while **moving to account for global loading in their estimates as appropriate**, especially the contribution via trans-Pacific and trans-Arctic pathways to the North American mercury pool. **Such improvements are necessary if the outcome of control measures is to be predicted and subsequently demonstrated.**

Government agencies should increase dialogue between the policy and scientific arms of their organization to ensure that policy evolves from the most current and robust science.

Investigation of further possible effects of mercury on human health must be sustained to ensure that the most current and relevant information on human health effects is available while considering further reductions in releases of mercury from anthropogenic sources.

Canada, the United States and Mexico should continue and enhance their coordinated approach, with joint technical programs where possible, in all aspects of mercury research and policy development.

The dialogue between the IJC and the Commission on Environmental Cooperation on the mercury issue be maintained and opportunities for interaction with other international and intergovernmental organizations, such as those arising from the United Nations Environmental Program Mercury Global Assessment, be acted upon.

The complete workshop summary is available through the IJC Great Lakes Regional Office or the offices of the Commission for Environmental Cooperation.

1.6 MODELING OF ATMOSPHERIC MERCURY TRANSPORT AND DEPOSITION TO THE GREAT LAKES BASIN USING THE NOAA-HYSPLIT MODEL

1.6.1 Introduction

Mercury contamination is increasingly recognized as a critical environmental issue in many parts of the world, and the Great Lakes basin is no exception. In addition to significant public health concerns, addressed elsewhere in this document, there are substantive economic implications associated with this contamination as well. The presence of persistent toxic substances in freshwater and marine fish has resulted in restrictions on consumption of various forms of seafood, and, as shown in Figure 3, mercury levels are driving the increased placement of advisories on individual water bodies. As limits on human consumption of many commercially- and recreationally-important freshwater and marine species are tightened further, the negative economic impact becomes more pronounced.

Atmospheric deposition is a significant loading pathway for mercury, and in many cases is the dominant loading pathway to many ecosystems. Available evidence suggests that this is true for the Great Lakes. Mass balance calculations for Lake Michigan (Mason and Sullivan, 1997) and Lake Superior (Dolan *et al.,* 1993) indicate that atmospheric deposition accounts for approximately 75 percent of the overall mercury loading to these lakes.

Building on its experience in modeling the sources and input of dioxin to the Great Lakes basin, the IAQAB agreed that its contribution under the 2001-2003 biennial Great Lakes priorities of the IJC would be an attempt to model the transport and deposition of mercury from continental sources to the basin.

Rationale

While there have been several mercury modeling efforts in North America (Bullock *et al.,* 1998; Bullock and Brehme, 2002; Dvonch *et al.,* 1998; Lin *et al.,* 2001; Pai *et al.,* 1997; Seigneur *et al.,* 2001; Shannon and Voldner, 1995; Xu *et al.,* 2000a,b,c), none has developed detailed source-receptor relationships for the Great Lakes, as advocated in Annex 15 of the *Great Lakes Water Quality Agreement*. During the IJC's 1997-1999 biennial priority cycle, the IAQAB focused on refinement of the application of the NOAA-HYSPLIT model to the transport and deposition of polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/F or "dioxin") from across Canada and the United States to the Great Lakes basin (*1997-99 Priorities and Progress Under the Great Lakes Water Quality Agreement*, 1999).

In addition to the dioxin application, the NOAA-HYSPLIT model has been extensively evaluated in simulations of the transport and deposition of a variety of compounds and contaminants, and has been shown to be capable of providing outputs and estimates that compare well with ambient measurements and other comparable data (Cohen *et al.,* 1997; Draxler and Hess, 1998; Draxler, 1991, 2000; Stein *et al.,* 2000; Rolph *et al.,* 1992, 1993; McQueen and Draxler, 1994, Draxler *et al.,* 1994). In the dioxin modeling analysis, it also provided results consistent with ambient measurements (Cohen *et al.,* 2002). One of the principal advantages of using this methodology is that, if adequate supporting data, particularly good quality emissions inventories, are available unusually detailed source-receptor relationships can be derived.

In considering application of the NOAA-HYSPLIT atmospheric transport model to the determination of mercury emission sources of significance to deposition in the Great Lakes basin, several issues integral to the nature of mercury must be examined and managed.

Nature of the Contaminant

There are many mercury species of environmental importance. However, relatively little is known about the precise speciation of mercury in the atmosphere. Notwithstanding this limited understanding, scientists generally classify atmospheric mercury into three general categories (Schroeder and Munthe, 1998); some selected information on the behavior of these three classes of mercury in the atmosphere is given in Table 3.

Elemental mercury Hg^0

Elemental mercury is simply atomic mercury. Its limited solubility, shown by the value of its Henry's Law Constant, results in only small amounts being dissolved in atmospheric water droplets and its relative volatility means that little will be adsorbed onto the surface of aerosol particles; thus, it exists primarily in the gas phase in the atmosphere. In most locations, particularly those at some distance from large emission sources, the great majority of the mercury in the atmosphere (~ 95 percent) would be found in this form.

TABLE 3
Typical ambient air concentrations and atmospheric duration of mercury species

	Concentration ng/m^3	Henry's Law Constant	Temporal and Spatial Scale
Elemental Mercury: – Hg^0	1 – 3	0.3	Global Lifetime: Months to a year
Divalent Mercury (e.g. $HgCl_2$)	0.01 – 0.1	0.00004	Local/Regional Lifetime: ~ 1 – 10 days
Particulate Mercury – Hg(p)	0.01 – 0.1	–	Local/Regional Lifetime: ~ 1 – 10 days

Oxidized mercury Hg(II)

When in the gas phase, this form of mercury is frequently referred to as reactive gaseous mercury. Little is known about the actual species that comprise the pool of oxidized mercury in the atmosphere, although one species of probable significance is mercuric chloride ($HgCl_2$). This form of mercury is defined to some extent through its behavior in measurement devices and by its water solubility and/or its lower volatility or relative adherence to some surfaces. It predominantly exists in the gas phase and in atmospheric water droplets (where they are present). It also has an affinity for and can be adsorbed to soot in the atmosphere, and can be associated with this substance particularly within the aqueous droplets. At most locations, oxidized mercury makes up only a small percent of the total mercury in the atmosphere.

Particulate mercury Hg(p)

Perhaps even less is known about the precise species that make up the pool of particulate mercury in the atmosphere. This form of mercury is also defined operationally, as the amount of mercury associated with particulate matter in the atmosphere. This is not a reference to discrete particles of mercury, but rather to mercury species within and on the surface of atmospheric particles. Mercuric oxide (HgO) may be an important Hg(p) species, but this is not known with any certainty. It is likely that, on average, particulate mercury may be less bioavailable after being deposited to ecosystems. Like oxidized mercury, this form of mercury also typically accounts for only a small percent of the total concentration of atmospheric mercury at most locations.

Interaction of Mercury Species and Other Constituents in the Atmosphere

The atmospheric chemistry of mercury is complex (Ryaboshapko *et al.,* 2002, 2003; Schroeder *et al.,* 1991; Lin and Pehkonen, 1999). Each of the above three forms of mercury has distinctly different wet and dry deposition behavior, and the interconversion of one form to another in the atmosphere must be considered in any realistic atmospheric model.

Elemental mercury in the gas phase can be oxidized to Hg(II) by a number of agents, including ozone (O_3) (Hall 1995), hydrogen peroxide (H_2O_2) (Tokos *et al.,* 1998), chlorine (Cl_2), (Calhoun and Prestbo, 2001) and hydroxyl radical (OH) (Sommar *et al.,* 2001), and, in the aqueous phase (e.g. cloud droplets), by several different oxidizing species, including O_3 (Munthe 1992), OH^{-1} (Lin and Pehkonen, 1997), hydrochlorous acid (HOCl), and hypochlorite ion (OCl^{-1})(Lin and Pehkonen, 1998).

There also appear to be important heterogeneous halogen-mediated oxidation reactions that play a very significant role in the "Arctic sunrise" mercury depletion events (Lindberg *et al.,* 2002). Measurements of relatively elevated concentrations of Hg(II) at high altitudes (Landis 2001) suggest that these or similar reactions may also be of significance in the upper atmosphere, but this possibility requires further examination.

In addition, divalent mercury Hg(II) can be reduced to elemental mercury (Hg^0) by sulphurous acid (HSO_3^{-1}), formed in pH-dependent amounts from dissolved sulphur dioxide (SO_2). Until recently, it was thought that the hydroperoxyl radical (HO_2) also reduced Hg(II), but recent determinations by Gardfeldt and Jonnson (2003) have indicated that this reaction may be of much less importance than it originally appeared to be.

The chemical behavior of Hg(p) is not well understood. For example, the extent to which it is dissolved whenever the particle it is associated with becomes a droplet is uncertain, and the assumed solubility varies among different atmospheric chemistry models. Moreover, it is known that there is a reversible adsorption/desorption of

dissolved Hg(II) to and from soot surfaces within a droplet (Seigneur *et al.,* 1998), but, the relationship of adsorbed Hg(II) species and Hg(p) species has not been well characterized. In this NOAA-HYSPLIT modeling, it was assumed that Hg(p) is insoluble, but Hg(II) formed reversible complexes with soot in aqueous droplets.

Emissions: Speciation and Subsequent Transformations

Most natural emissions or re-emissions of previously deposited mercury are believed to be primarily elemental mercury (e.g. Schroeder and Munthe, 1998; Scholtz *et al.*, 2003; Gustin 2003). However, emissions from many significant current anthropogenic sources, such as coal-fired electrical utilities or municipal or medical waste incinerators, are often mixtures of the three forms. An estimation of the proportions of the various forms from different source types will be presented later in the discussion of specific emission data.

As mentioned earlier, each of the above forms of mercury can be transformed into the other in the atmosphere. Because these reactions are relatively prolonged, and given that wet and dry deposition of elemental mercury is a relatively inefficient process, the atmospheric lifetime of Hg^0 is believed to be on the order of 0.5-1 year (e.g. Tokos *et al.*, 1998) allowing for the global distribution of this mercury species. Background concentrations of approximately 1.5-2.5 ng/m^3 arising from this global circulation are found worldwide, even in the absence of local sources.

The other forms of mercury are more readily deposited by wet and dry processes, and likely have typical atmospheric lifetimes of a few days to a few weeks. Thus, these forms, when emitted, typically have more local and regional impacts.

Because of the distinct atmospheric deposition behavior of the different species, it is crucial to have good estimates of both the amounts of each emitted from each source (i.e. a speciated emissions inventory) and the rates of the interconversion processes, which vary from point to point and over time in the atmosphere. These interconversion processes are dependent on a number of factors, including, for example, the presence and concentrations of other compounds in the atmosphere that oxidize or reduce mercury.

It is also important that ambient monitoring programs attempt to make measurements of each of these different forms; however, there are very few such measurements made. This is another of several limitations precluding a comprehensive understanding of atmospheric mercury phenomena.

Conceptual Model of Atmospheric Mercury Deposition

The conceptual model emerging for atmospheric mercury deposition to the Great Lakes (and other water bodies) can perhaps be summarized as follows (see for example, Vette *et al.*, 2002).

- The dry and wet deposition of mercury to the lakes is generally dominated by the Hg(II) and Hg(p) forms.

- In the lake, there are a number of conversion processes, and some of the deposited mercury is eventually transformed to methylmercury, the most environmentally significant species, and is then available for bioaccumulation in the ecosystem.

- In the lake, some mercury - believed to be largely Hg^0 (Vette *et al.,* 2002) - resides in the water column in dissolved form or associated with suspended sediments.

- Some mercury in the lake is incorporated into the sediments; it may reside there or be resuspended, or be incorporated, after conversion to methylmercury by bacteria in the sediments, into the food chain.

- Some elemental mercury - and potentially a small amount of the methylmercury (Rolfhus *et al.*, 2003) - in the lake may volatilize from the lake surface for transport via the atmosphere to other locales, representing a loss of mercury from that particular waterbody.

- This volatilization or surface exchange process of Hg^0 across the lake's surface is believed to be comparable to that of PCB and other similar semi-volatile pollutants; the direction and magnitude of the net flux will depend on the water and air temperatures, wind speed, and other meteorological and aquatic variables, as well as the relative concentrations of mercury in the lake and in the air above the lake.

- Estimates for Lake Michigan (Vette *et al.*, 2002; Landis and Keeler, 2002) based on measurements made in the Lake Michigan Mass Balance Study suggest that the net direction of the elemental mercury Hg^0 flux during that study was upwards (i.e. out of the lake); this may also be the case for Lake Michigan currently.

- Overall, the mercury in the lakes can be considered to be dry and wet deposited downward in the form of Hg(II) and Hg(p), and some portion of it revolatilized upwards in the form of Hg^0; if more is deposited than revolatilized, then the mercury concentrations in the lake ecosystem will increase, and vice versa.

1.6.2 Modeling Methodology

Atmospheric Transport and Dispersion Model

The NOAA-HYSPLIT_4 model (Hybrid Single-Particle Lagrangian Integrated Trajectory model, Version 4) (Draxler and Hess, 1998), augmented by a spatial and chemical interpolation procedure (Cohen *et al.*, 2002), was used to estimate source-receptor relationships. In this application of the HYSPLIT model, puffs of pollutant were considered to be emitted from each given source location. The subsequent advection and dispersion of the pollutant puffs was then simulated using meteorological data supplied to the model. A full year (1996) of meteorological output from NOAA's Nested Grid Model (Rolph 1997) was used for the year-long simulations in this study. These data had a horizontal resolution of 180 km, 11 vertical levels up to 6000 meters elevation, and a two-hour temporal resolution.

The use of more highly resolved meteorological data would no doubt improve the accuracy of the simulation, especially in the prediction of concentrations and deposition at specific locales (e.g. in the model evaluation exercises described below). However, it is not likely that the overall deposition and the source-receptor relationships for the Great Lakes estimated here would be significantly affected by use of more highly resolved meteorological data. This supposition could be confirmed in future work through the use of such data, which have recently become available.

The HYSPLIT_4 model has recently been used to simulate atmospheric fate and transport of dioxin to the Great Lakes (Cohen *et al.*, 2002) and many of the model modifications made for that study have been retained in the present application. Several mercury-specific changes and additions were incorporated into the model for this analysis.

Mercury, like other pollutants, is also subject to dry deposition phenomena, by which it is transported down to the earth's surface by atmospheric dispersion and then some portion of it adheres to various earth surfaces such as water, trees, other vegetation or buildings.

The most significant of these regarded the treatment of atmospheric chemistry.

Simulating the Atmospheric Chemistry of Mercury

In the dioxin modeling, only a gas-phase reaction with OH and gas- and particle-phase photolysis were considered in the chemistry module, and it was assumed that no conversion from one congener to another occurred. However, an adequate simulation of mercury's atmospheric chemistry requires a more sophisticated analysis.

The mercury chemical equilibrium and reaction scheme used in this application is similar to that currently being employed in other atmospheric mercury models (e.g. Ryaboshpko *et al.*, 2002, 2003) and is summarized conceptually in Figure 4.

Ambient concentrations of O_3, SO_2, and soot and the pH and aqueous concentration of Cl^{-1} were estimated from ambient data, and concentrations of other key reactants (OH, Cl_2, etc.) were estimated using other empirically-based procedures.

Simulating Dry and Wet Deposition of Atmospheric Mercury

As noted previously, elemental mercury is only sparingly soluble in water, and it is not efficiently incorporated into wet deposition. As a result, the preponderance of mercury in wet deposition is in the oxidized or particulate forms. Mercury, like other pollutants, is also subject to dry deposition phenomena, by which it is transported down to the earth's surface by atmospheric dispersion and then some portion of it adheres to various earth surfaces such as water, trees, other vegetation or buildings. In addition to this downward dry deposition component, there is also generally an upward flux of mercury from land and waters (e.g. from natural sources or previously deposited anthropogenic emissions).

At any given location and time, the relative magnitude of the downward and upward components will vary, and this relative magnitude will generally be different for each form of mercury. The general consensus of the scientific community is that the upward component of the surface-exchange flux of Hg(II) and Hg(p) at most locations is relatively insignificant, (i.e. for these two forms, the net flux is almost always in the direction of deposition (down), and, as a reasonable, simplifying assumption, the upward flux phenomena for these two species is generally ignored). This approach has been taken in the atmospheric mercury modeling analysis discussed here; that is, only the downward flux of Hg(II) and Hg(p) has been modeled.

In addition, as a simplification of the deposition process, the approach of Bullock (2002) and others was followed, in which it was assumed that the total deposition of *elemental* mercury from direct anthropogenic emissions was roughly balanced by the volatilization of previously deposited emissions of *elemental* mercury from both natural and anthropogenic sources. That is, the net deposition of *elemental* mercury was assumed to be zero. A more sophisticated treatment of these phenomena would no doubt be beneficial, but the limited understanding of the relevant processes and a lack of measurement data to evaluate estimates make their inclusion somewhat impractical. Nevertheless, as discussed in more detail later, the ability of this and other models to satisfactorily explain ambient mercury concentrations and deposition provides evidence that this simplified approach is reasonably consistent with the overall net cycling of elemental mercury between the atmosphere and the earth's surface.

Only the *direct* deposition to the lake surfaces has been estimated in this modeling analysis. *Indirect* atmospheric contributions, resulting from deposition to a lake's watershed and subsequent transfer to the lake, have not been estimated as part of this modeling. Because their watersheds are smaller, relative to their size, than many other lakes, the Great Lakes probably receive proportionally less mercury from this indirect route than many other lakes.

Estimating the amount of mercury loading to the Great Lakes contributed through this indirect pathway is very uncertain, as there are few measurements of runoff and tributary inputs to the lakes. Moreover, determining the portion of such input that arises as a result of atmospheric deposition as opposed to direct discharges to the tributaries or natural mercury present in the ecosystem is difficult. Rolfhus *et al.* (2003) have estimated that total tributary input to Lake Superior represented approximately 27 percent of the total loading to the lake, based on measurements made in year 2000. Landis and Keeler (2002) estimate that tributary inputs account for approximately 16 percent of the loading to Lake Michigan, based on 1994-95 measurements. Indirect atmospheric deposition would account for a portion of these contributions, but the fraction is unknown. The METAALICUS project, described in section 1.4 of this report, represents an attempt to further understand these processes. The knowledge gained in that project should support development of more accurate estimates of such phenomena for the Great Lakes.

Methodology to Estimate Source-Receptor Relationships

A procedure was developed to establish linkages between significant point and areal sources of mercury throughout the United States and Canada, and the subsequent deposition of this contaminant to the Great Lakes basin. In this technique (Cohen *et al.*, 2002) an interpolation procedure is used to estimate detailed source-receptor relationships. To conduct the analysis, explicit HYSPLIT modeling of emissions was performed for a limited number of selected source locations. The impact of any given source on the Great Lakes was estimated based on a weighted average of the impact of the four explicitly modeled locations that would be nearest to the source in question.

To account for the varying proportions of different Hg species being emitted from different sources, separate unit-emissions simulations of Hg(II), Hg^0, and Hg(p) emissions were made at each standard source location. The impact of a source emitting a mixture of Hg^0, Hg(II), and Hg(p) was estimated based on a linear combination of these pure-component unit emissions simulations. In sum, both spatial and chemical interpolation procedures were used to estimate the impact of each source in the inventory on each of the Great Lakes.

Validity of the Interpolation Procedure

The spatial and chemical interpolation methodology used relies on the assumption that the atmospheric fate and transport of Hg from any given source is not influenced by the emissions from any other source. This assumption is believed to be generally valid, based on the following arguments:

- Mercury is present at extremely minute levels in the atmosphere. As a consequence, it will not affect meteorology. Thus, meteorological parameters, such as wind speed and direction, temperature, humidity, precipitation, etc., can be estimated independently and provided to the model.

- Also, most species that react with mercury compounds (e.g. SO_2) are generally present at much higher concentrations than the mercury compounds. Other species (e.g. OH) generally react with many compounds other than mercury, so, while present in trace quantities, their concentrations cannot be strongly influenced by their interactions with mercury.

- Wet and dry deposition processes themselves are not fundamentally affected by the presence of mercury and are generally considered to be *first order* with respect to mercury concentrations. In this context, first order means that the process rate is estimated with an expression of the form $rate = k \cdot c$, where k is a parameter which may depend on a number of factors, but which does not depend on the concentration of mercury, c.

- In addition, the current understanding of mercury's atmospheric chemistry does not include any chemical reactions or equilibrium relations that are not first order with respect to mercury.

- Finally, vapor/particle, vapor/droplet, and droplet/soot equilibrium relations can all be expressed as a ratio of the concentrations in different phases. A reasonable assumption can then be made that every mercury-containing compound has the same proportional chance (governed by this equilibrium ratio) of being in any given phase. Thus, the presence of mercury from another source is not expected to significantly affect the interphase distribution of mercury from any other source.

In consideration of all of the above factors, the assumption that emissions of mercury from one source be considered as independent of emissions of mercury from other sources appears justified. This assumed independence is likely to be valid for the modeling of many other trace pollutants in the atmosphere, but is certainly not valid, for example, for emissions of volatile organic compounds and nitrogen oxides.

Results of the Interpolation Procedures: Transfer Coefficients

Figure 5 shows the model-estimated transfer coefficients to Lake Superior for emissions of Hg^0, Hg(II) and Hg(p). These transfer coefficient maps show the ratio between the deposition flux to Lake Superior (micrograms of mercury (of all forms) deposited per year per km^2 of lake surface) and hypothetical continuous emissions (grams of mercury emitted per year from a given location) of the given form of mercury over the entire year 1996 from any given location throughout the modeling domain. It is important to stress that these maps do not incorporate emissions data. They simply represent the relative propensity of emissions from any given location for deposition in Lake Superior, based on the simulated atmospheric transport and fate of mercury. From these maps, it can be seen that, for essentially any given source location within the modeling domain, emissions of Hg(II) would result in the highest deposition in the lake, followed by emissions of Hg(p). In contrast, emissions of Hg^0 are predicted to result in significantly less relative deposition.

These results are consistent with the general understanding of the relative atmospheric behavior and fate of these different forms of mercury. Hg(II) is very water soluble, with relatively strong surface adhesion properties, and is therefore much more likely to be subject to wet and dry deposition. For example, Hg(II) can be wet-deposited from within precipitating clouds and even from below these clouds, due to its very high water solubility. Hg(p) can also be wet-deposited relatively efficiently if its host particles find themselves in precipitating clouds. In contrast to these forms, Hg^0 is only sparingly water soluble and relatively volatile — thus its potential for wet and dry deposition is comparatively limited. These fundamental considerations are the basis for the relatively long atmospheric lifetimes estimated for Hg^0 (~ 0.5 - 1 year), but relatively short atmospheric lifetimes for Hg(II) and Hg(p) (Schroeder and Munthe, 1998). Indeed, it is often the slow atmospheric conversion of Hg^0 to Hg(II) and/or Hg(p) which is required as a step to the eventual deposition of mercury.

As mentioned above, any given emissions source will generally emit a mixture of these different forms. For example, while there are significant variations based on the type of coal being burned, the type of pollution control equipment present, and other factors, on average, coal-fired power plants emit a mixture comprised of approximately 50 percent Hg^0, 45 percent Hg(II), and five percent Hg(p). Figure 6 shows the model-estimated transfer coefficients for this average coal-combustion emissions mixture for each of the Great Lakes. The patterns are similar for each of the Great Lakes, and show that, as would be expected, the propensity for atmospheric deposition contributions is reduced substantially as the distance from the lake increases. Since the prevailing winds are from the west, potential contributions from regions west of a given lake tend to be greater than potential contributions from similar distances east of the lake. As another way of understanding this phenomenon, the contribution potential falls off more steeply east of the lakes because winds that could transport mercury from sources in these regions occur less frequently.

For the results presented here, a total of 84 such standard source locations, many of which were clustered around the basin, were used (the small circles shown in Figures 5 and 6). Analyses using more than 84 standard source locations were also performed, but the results did not vary significantly from this 84-location analysis. Therefore, as was found with the earlier dioxin analysis, it is believed that the interpolation procedure using these 84 locations is providing estimates of adequate accuracy.

In these transfer coefficient maps, it can be seen that there are occasionally small regions around a few of the standard source locations that appear to be artifacts of the interpolation procedure. For example, in the Hg(p) map in Figure 5, there is a small circular region around the standard point in the northern, central portion of the map (in the Northwest Territories, about 500 km west of Hudson Bay). The fact that this small region surrounding the standard point appears to have a slightly lower potential for transport to the lakes in comparison to the surrounding region is probably indicative of a slight loss of accuracy in the interpolation procedure due to the fact that the standard points are relatively sparsely distributed in this region and also, possibly because the location is close to the edge of the modeling domain. More standard points in regions such as this could be added, and the modeling domain expanded; these alterations would make the transfer coefficient map slightly more accurate. However, it was not deemed necessary to expend the computational resources to accomplish this, as the contributions of mercury from these areas to the Great Lakes was inconsequential due to the fact that the transfer coefficients were relatively low and there were no significant sources in these regions.

Note that the transfer coefficient maps shown here are slightly different from the transfer coefficient maps shown in earlier analyses (e.g. IJC Priorities Report 1997-99). Previously, it was the fraction of the emission being deposited to the entire lake that was being mapped. Because each of the Great Lakes is a different size, the transfer coefficient patterns appeared to be very different, but this was primarily the lake-size effect. That is, in the previous version of these maps, the size of the lake mattered, because all things being equal, more of the emissions from any given location would be deposited in a larger receptor than a smaller receptor. In the current maps, the values have been normalized by the size of the lake, making the mapped transfer coefficients independent of this factor. Following the procedure illustrated below, however, one can convert the values in the current maps to those in the previous form.

Mercury Emissions Inventory

In any analysis such as this, ideally all critical information would be referenced to the same time period, including the emissions inventory, meteorological data, and ambient monitoring data for model evaluation. Unfortunately, as discussed below, there was no one year for which comparable emissions inventories for the United States and Canada existed. As the best compromise, the nominal year for this analysis was chosen to be 1996, (i.e. 1996 meteorological data were used to drive the model, and 1996 ambient data were used for model evaluation). Therefore, the goal was to utilize emissions inventory data representative of 1996 to the greatest extent possible.

A mercury emissions inventory for the United States was obtained from the U.S. EPA (Ryan 2001). The inventory contains annual emissions estimates for most anthropogenic sources of mercury. For coal-fired electricity generation boilers, municipal waste incinerators, and medical waste incinerators, the estimates in this inventory were for 1999, while the remainder were reported to be representative of 1996 emissions.

The inventory was further modified in recognition that one source category (coal combustion in commercial, industrial, and institutional boilers and process heaters) appeared to be under-represented in this inventory, and so data from an alternative 1995-1996 U.S. EPA inventory (Bullock 2000; U.S. EPA 1997) was utilized for this source type. Also, because significant reductions in emissions from United States municipal waste incinerators and medical waste incinerators occurred between 1996 and 1999 (Mobley 2003), data from this alternative inventory of 1995-1996 emissions for these categories were used.

The coal-fired utility emissions estimates for 1999 were used however, as they were based on a significant amount of source testing and were estimated with a much more sophisticated approach than used in previous inventories. Emissions from coal-fired boilers appear to have been fairly similar in 1996 and 1999, at least in total (Mobley 2003).

The United States inventory contained a total of 17,513 discrete point sources with specific locations. As is common practice in emissions inventories, certain source categories (e.g. mobile sources, residential fuel consumption) were not estimated at precise locations but were estimated at the county level. There were 52,673 of these area sources in the inventory, representing approximately 17 such source types, on average, in each of the 3141 United States counties. For such area sources, for the purposes of the modeling analysis, it was assumed that the source location was the centroid of each county.

For Canada, the latest available emissions inventory was obtained (Niemi *et al.*, 2001). In this 1995 inventory there were 583 point sources. Area sources in this inventory were specified on a 50-km grid in the Great Lakes region and a 100-km grid in the remainder of the country. On the 473 50-km grid-squares and 1140 100-km grid-squares, there was an average of approximately 22 area source categories per grid square. Analogous to the United States

The geographical region of significant contributions is somewhat distinct for each lake, as would be expected given their different locations and the variations in the extent of industrialization and urbanization in each basin. For example, there are significant contributions to Lake Superior from regions within approximately 1000 km west of the lake, but the relative contribution of this region to the other lakes is lower, due to both the increased remoteness and the presence of adjacent relatively large point and areal sources. For Lake Michigan, the contribution from the Chicago region stands out, due to its significant emissions and proximity to the lake; this particular region appears to be somewhat important for the other lakes as well. For Lake Erie and Lake Ontario, contributions from the Ohio River Valley appear to be very significant, again, due to the high emissions in this region and the comparative proximity to these lakes.

inventory, area sources in the Canadian inventory were assumed to be located at the centroid of each grid square. It was believed that there were very few (if any) significant changes in Canadian emissions between 1995 and 1996 (Niemi 2001) and so this 1995 inventory was assumed to be representative of 1996 Canadian emissions.

To summarize the inventory used in this modeling analysis, Figure 7 shows the geographical distribution of the total anthropogenic mercury emissions in the above inventory throughout the United States and Canada. The annual emissions in the two countries are broken down by source category in Figure 8 and on a *per capita* basis in Figures 9 and 10. The relative importance of coal combustion in the United States and metallurgical processes (e.g. smelting) in Canada is apparent. It should be noted that emissions from metallurgical processes in Canada have been sharply curtailed in more recent years.

The populations used to normalize the national emissions to a *per capita* basis were 265,000,000 for the United States and 30,000,000 for Canada from 1996 census estimates made in each country. Displaying the *per capita* values rather than the simple totals allows for a conceptual comparison of United States and Canadian contributions. If the simple total emissions are shown, Canadian values would in most cases appear very small relative to the United States values. The use of *per capita* values may perhaps make the comparison between the two countries more meaningful, as the effect of the dramatically different populations is removed. Any of the *per capita* values can be converted to the total emissions for a given country by multiplication by that country's population.

The United States inventory contained estimates of emissions of the three forms of mercury: elemental (Hg^0), ionic (Hg(II) and particulate (Hg(p), but the Canadian inventory did not. Therefore, the United States data also were used to make estimates of the proportions of the different forms emitted from the corresponding source categories in Canada. Figure 11 shows the average emissions profile or distribution of mercury species in the emissions from individual source categories; the combined United States / Canada annual emissions of each form of mercury from each source category are shown in Figure 12. Unfortunately, there have been relatively few measurements of the proportion of the three forms of mercury emitted from various source categories, and so this aspect of the inventory is particularly uncertain. As is discussed throughout this chapter, the atmospheric fate of the different emitted forms is quite distinct. Accordingly, source-receptor relationships are strongly dependent on the emissions profile of the individual source, and the accuracy of atmospheric mercury modeling analyses would increase if more and better information regarding this issue becomes available.

Only anthropogenic emissions from the reference year(s) from sources in the United States and Canada have been explicitly included in this analysis. Other modeling exercises have suggested that the contribution of global sources to atmospheric deposition to the Great Lakes accounts for on the order of 13 percent (Shannon and Voldner, 1995) to ~20 percent (Dastoor, 2003, personal communication) of the total deposition, and inclusion of the global input in this HYSPLIT_4-based modeling methodology is planned for the future.

There are significant uncertainties in both the United States and Canadian inventories and in the application of such inventories in this modeling analysis. Some potentially prominent sources (e.g. electric arc furnaces) were not explicitly included, and, while emissions from some source categories (e.g. coal-fired power plants) have been measured with some regularity, other categories have been rarely measured. As a result, the annual emissions estimates are uncertain for many sources. Information on the temporal variation of emissions was not available, and so all emissions sources in the inventories were assumed to have been continuous and constant throughout the year. This is probably a reasonable assumption for coal-fired power plants (the largest-emitting source category in the inventory), but is less appropriate for many other source categories. Even for sources that were relatively continuous, data for episodes, such as maintenance or upset-related shut downs, were not included in the inventory. Weather patterns can be highly episodic and significantly alter source-receptor relationships; these temporal uncertainties will certainly compromise the accuracy of the estimated concentrations or deposition at a given location at any given time. However, this analysis has been conducted over the course of an entire year (and primarily, annual estimates have been generated), and this may reduce the uncertainty introduced by this variability.

Linking Transfer Coefficients and Emissions Data

To complete the modeling activity, it is necessary to combine the transfer coefficients and the emission inventories described previously. This combination will be demonstrated by means of a simple example. In the map in Figure 5 for Hg^0, it can be seen that there is, for example, a region that refers to transfer coefficient values in the range 0.01 to 0.02 (μg total Hg deposited/km^2-yr)/(g emitted/yr). Suppose there was a mercury source emitting 100 grams of Hg^0 somewhere in that region. What the estimated transfer coefficient means is that the estimated deposition flux of mercury resulting in Lake Superior from that source will be:

flux

= 100 (grams Hg^0 emitted/yr) • 0.01 to 0.02 (μg total Hg deposited/km^2 - yr)(grams Hg^0 emitted/yr)

= 1 to 2 (μg total Hg deposited/km^2 - yr)

To get the actual amount of mercury contributed to the entire surface of Lake Superior from this hypothetical source through atmospheric deposition, one would multiply by the surface area of the lake.

deposition amount

= flux • surface area

= 1 to 2 (μg total Hg deposited/km^2 - yr) • 81,200 (km^2)

= 81,200 to 162,400 (μg total Hg deposited/yr)

= 0.08 to 0.16 (grams total Hg deposited/yr)

Thus, the 100 grams of Hg^0 emitted from the hypothetical source over the year is estimated to result in a deposition to Lake Superior of 0.08 to 0.16 grams of total mercury (i.e. mercury in all forms). Given that the source was 100 g/yr, 0.08 to 0.16 also expresses the percent of the emissions deposited at this location.

The above is a simplified description of how the transfer coefficients and emissions data are combined in the model methodology. In practice, the multiplication of the emissions inventory map and the transfer coefficient map is done numerically, for each mercury form emitted by each source. This procedure results in an estimate of the atmospheric deposition impact of each source in the emissions inventory to each of the Great Lakes.

1.6.3 Model Results

Overall Atmospheric Deposition to the Great Lakes

The overall model-estimated deposition amount (kg/yr) and flux (g/km^2-yr) of mercury to each of the Great Lakes is shown in Figures 13 and 14, respectively, for both wet and dry deposition. It can be seen that both forms of deposition appear to be important. Lake Michigan is seen to have the greatest deposition amount, while Lake Erie appears to have the highest deposition flux.

Geographical Distribution of Atmospheric Deposition Contributions of Mercury

As mentioned above, the modeling methodology described herein generates estimates of the contribution of each source in the emissions inventory (~106,000 discrete records (sources, either point or area) in the applied United States / Canadian inventory) on each receptor of interest. As a way of summarizing these results, Figures 15-19 show the geographical distributions of mercury source contributions to atmospheric deposition in each of the Great Lakes.

It can be seen that mercury deposition to each of the lakes arises from throughout the region, and that even distant sources can contribute significant amounts. For example, even sources in Florida appear to be able to contribute significant amounts of mercury to each of the Great Lakes. The geographical region of significant contributions is somewhat distinct for each lake, as would be expected given their different locations and the variations in the extent of industrialization and urbanization in each basin. For example, there are significant contributions to Lake Superior from regions within approximately 1000 km west of the lake, but the relative contribution of this region to the other lakes is lower, due to both the increased remoteness and the presence of adjacent relatively large point and areal sources. For Lake Michigan, the contribution from the Chicago region stands out, due to its significant emissions and proximity to the lake; this particular region appears to be somewhat important for the other lakes as well. For Lake Erie and Lake Ontario, contributions from the Ohio River Valley appear to be very significant, again, due to the high emissions in this region and the comparative proximity to these lakes. In general, for each of the lakes, contributions from the United States appear to be somewhat greater than contributions from Canada.

The geographical distribution of mercury contributions is illustrated in another manner in Figure 20, where the emissions and contributions are shown as a function of distance away from each lake. For Lake Superior and Lake Huron, significant deposition occurs from sources 200-1500 km away from the lakes. For the other Great Lakes, there is a more significant contribution from sources closer to the lakes, but, even for these lakes, the regional and long-range contribution is significant.

Atmospheric Deposition Contributions of Mercury from Different Source Types

In light of the limitations outlined in the discussion of emissions inventories earlier in this report, ascribing portions of the deposition to different source categories is an imprecise exercise. However, preliminary estimates of the impact of different source categories on deposition to the Great Lakes can be developed and are shown in Figure 21.

This figure illustrates the *per capita* contribution from four broad source categories comprising the total inventory - fuel combustion, incineration, metallurgical operations, and manufacturing. This last category also includes emissions from a few other non-manufacturing categories. One feature is the apparent relative importance, even on a *per capita* basis, of fuel combustion in the United States to mercury deposition in the Great Lakes. Most of the mercury emissions from this fuel combustion category come from various coal combustion activities (see Figure 10), predominantly the coal fired electrical utility sector. In Canada, by comparison, on a *per capita* basis, metallurgical operations appear to have been a dominant source sector in 1996.

As noted earlier, during and since the period under consideration by the model - the mid point of the previous decade - substantial reductions have been achieved in emissions from both municipal and medical waste incineration. The Canadian metallurgical operations have subsequently also lowered their mercury emissions dramatically. However, emissions from the coal fired electrical utility sector have remained relatively stable while governments

consider the merits of various proposed mercury emission reduction programs for this sector.

1.6.4 Model Evaluation

In any modeling study, it is important to ground-truth the predictions to ensure that the simulations are providing reasonable results. Since the science of atmospheric mercury modeling is evolving, and there are still significant uncertainties in the understanding of key processes, such model evaluation exercises are perhaps even more critical.

Previous HYSPLIT Model Evaluations

As noted earlier, the HYSPLIT model has been extensively evaluated over many years for simulations of a variety of compounds, and has been shown to be capable of providing reasonable simulations. For example, as mentioned earlier, many aspects of this modeling methodology were used in a recent dioxin modeling analysis that provided results consistent with available ambient measurements. In addition, this mercury modeling methodology has been applied in an ongoing mercury modeling intercomparison study by Meteorological Synthesizing Center-East for the European Monitoring and Evaluation Program (Ryaboshapko *et al.*, 2003) over a European modeling domain, along with several other atmospheric mercury models from research groups around the world. In this exercise, the HYSPLIT_4-based mercury-modeling methodology showed a very encouraging capacity to simulate atmospheric mercury, and was comparable in its capabilities to the other models.

Comparison with Results from the Lake Michigan Mass Balance Study

A ground-truthing exercise has been carried out by comparing the model predictions deposition to Lake

In response to encouragement from several quarters, including recommendations made by the IJC in its *Tenth Biennial Report on Great Lakes Water Quality*, mercury measurement capabilities have been added to several stations in the binational Integrated Atmospheric Deposition Network.

Michigan with measurement-based estimates obtained during the Lake Michigan Mass Balance Study (Landis and Keeler, 2002; Vette *et al.*, 2002). An advantage of this comparison is that it is for an entire lake (rather than a single location) and it is one of the Great Lakes. This comparison is shown in Figure 25 for estimated wet deposition of Hg(II) and Hg(p) (combined), dry deposition of Hg(II) and Hg(p), and total mercury deposition. The ranges shown for the Lake Michigan Mass Balance Study's data are the reported standard deviations (Landis and Keeler, 2002) for the estimates, and are a measure of the uncertainty associated with these estimates. Analyses to estimate uncertainties in the HYSPLIT-based model estimates have not yet been carried out, but a rough estimate of the uncertainty (+/- 25%) has been indicated for these data in Figure 22.

The Lake Michigan Mass Balance Study measurement-based estimate of net Hg^0 deposition is also shown – actually a net evasion from the lake of 453 +/- 144 kg/yr (thus, it is shown as a negative number, in contrast to the other values, which represent downward deposition to the lake). As discussed above, this quantity was not estimated in the modeling analysis, and so a comparison is not possible.

Precise agreement between the two sets of estimates would also not be anticipated, as the modeling results are for 1996, and the Lake Michigan Mass Balance Study's measurements were carried out in 1994-1995. There were undoubtedly distinct weather patterns and different precipitation amounts in these two periods, and perhaps even more importantly, mercury emissions during these two periods probably changed significantly. For example, during the 1994-1996 period, there were significant reductions in emissions from medical waste incinerators (due to the closure of many facilities) and municipal waste incinerators (due to closures, retrofits, and changes in waste stream composition). Moreover, the modeling analysis did not include contributions from sources outside the United States and Canada, nor did it include the contribution of natural emissions. For all these reasons, one would expect that the model predictions would be somewhat less than that measurement-based deposition estimate. Nevertheless, it is encouraging to note that the overall model-predicted deposition is the same order of magnitude as the measurement-based estimate, and the difference between the two is in the expected direction.

Additional Model Evaluation Exercises Underway

A detailed evaluation procedure is underway for the NOAA-HYSPLIT mercury modeling analysis in which model outputs or predictions are being compared in detail to available 1999 ambient mercury measurements. There are several data sets that are potentially available for this purpose, including the following: 1. weekly mercury wet deposition measured at 21 sites in the Mercury Deposition Network for some or all of 1996; 2. ambient concentrations and event-based wet deposition measurements at several sites in the Great Lakes region (Hoyer 1995; Keeler 2001); 3. ambient concentrations and event-based precipitation wet deposition measurements near Lake Champlain, NY (Burke *et al.*, 1995); 4. ambient concentrations and/or wet deposition measurements at several sites in Canada (Kellerhals *et al.*, 2000; Beauchamp *et al.*, 1997; Poissant and Pilote, 1998); and 5. measurements of ambient concentrations and wet deposition at several locations in the mid-Atlantic region (Mason *et al.*, 1997ab).

In response to encouragement from several quarters, including recommendations made by the IJC in its *Tenth Biennial Report on Great Lakes Water Quality*, mercury measurement capabilities have been added to several stations in the binational Integrated Atmospheric Deposition Network. In Ontario, the Point Petre and Burnt Island master stations and the Egbert satellite station have been measuring total gaseous mercury as of April 1998 or earlier and mercury in precipitation has been measured since on or before November of 2001. Speciation of reactive gaseous mercury and total particulate mercury is now underway at the Point Petre site as well. Plans to support mercury measurements at various Integrated Atmospheric Deposition Network stations in the United States are awaiting the required financial support.

Both governments are participating in a Lake Ontario Atmospheric Deposition Study (LOADS), under which mercury samples are being collected at Sterling, Potsdam and Stockton, New York, as well as at the Point Petre station referred to earlier. Shipboard mercury sampling is also an aspect of this program.

Given the uncertainties in the inventory and in the current state of understanding of mercury's atmospheric behavior, and certain limitations of this modeling analysis (e.g. global sources have not been included; temporal variation in emissions are not available), it is not expected that the model will be able to precisely match some or all of the measurements described above. Nevertheless, preliminary comparisons with several of these measurements show encouraging agreement and will be reported on in detail in forthcoming publications.

1.6.5 Conclusions

1. The NOAA-HYSPLIT atmospheric transport model, previously applied to the transport and deposition of dioxin to the Great Lakes basin, has been shown to be capable of linking local and distant sources of mercury emissions to subsequent deposition into the Great Lakes basin.

2. Given the limited comparative ambient data available, particularly estimates of dry deposition, and known weaknesses in the input data, especially those associated with emission inventories, exact comparison with monitoring data cannot be expected. While comparisons of model outputs to ambient measurements and the nature of the apparent biases continue to be explored, findings to date support the use of this model as an effective link between sources of mercury and subsequent deposition in the Great Lakes.

3. The model demonstrates that mercury deposition from anthropogenic sources to the Great Lakes is a regional and, to a certain extent, a continental issue and further reductions would be necessary on a national scale to achieve the goal of virtual elimination.

4. A small but significant portion of this deposition is likely associated with sources outside the United States and Canada, and these contributions could be examined in future work.

5. Modeling is generally necessary to develop source-receptor relationships; however the utility of models will depend largely on the quality of the comparison between their outputs and available ambient measurements. Therefore, adequate support for both modeling and measurement activities is essential to provision of the source-receptor information necessary for development and demonstration of effective mercury emission reduction policies.

6. Unfortunately, gaps remain in the understanding of the behavior of atmospheric mercury; the most notable of these are in the area of atmospheric chemistry.

7. The evaluation and improvement of models is severely limited due to the paucity of ambient and emissions measurements of mercury, particularly of the speciation of mercury in these measurement programs, and limited access to much of the existing data.

8. The limitations of existing emissions inventories were seen to play a significant role in this and other comparable modeling activities.

1.6.6 Recommendations

The IAQAB recommends the following to the IJC:

- **Every effort should be made to increase the detail, particularly on speciation of mercury, and accuracy associated with emissions inventories in the United States, Canada, and on a global basis. Some coordination in the production of inventories between the United States and Canada, resulting in largely seamless inventories applicable to the same base year, would be most helpful.**

- **Additional detailed ambient monitoring activities, including the completion of enhancements to the recently established mercury measurement capabilities of the Integrated Atmospheric Deposition Network, should be supported, and provisions should be put in place to make all completed measurements available in a timely fashion.**

- **A mercury modeling intercomparison study in North America, similar to that currently underway in Europe, could stimulate improvements while increasing confidence in the outcomes and linkages developed by atmospheric transport models. Improvements to the emissions data base and assembly of a comprehensive ambient measurement data set should be part of this model intercomparison.**

- **Following model intercomparison and comparison against measured data, these models should be used as a predictive tool in determining the potential impact on deposition of proposed mercury emission control programs currently under consideration in the United States and Canada.**

1.7 THE METAALICUS PROJECT: AN EXPERIMENTAL MERCURY MASS BALANCE

Throughout its engagement in the modeling of the atmospheric transport and deposition of mercury to the Great Lakes, the IAQAB has repeatedly acknowledged the need for a comprehensive model to track the fate of mercury from deposition into a waterbody to arrival in various biota in the water column. The METAALICUS project in the Experimental Lakes Area of Northwestern Ontario (Figure 23) is an attempt to track mercury from its initial deposition either on land, wetlands or open waters to its presence in fish.

A consortium of over 50 United States and Canadian researchers, augmented by scientists from Sweden and supported by governments, academia and the private sector, is using various application methods to simulate the deposition of minute quantities of different stable non-reactive isotopes of mercury to distinct segments of a headwaters lake. This small (8.3 ha) lake is bordered by a wetland area of 1.9 ha and an upland drainage area of 42 ha, and has a hydraulic retention time of three years. Small confined sub-areas also have been created in the lake for particular study.

The lake is currently subjected to a relatively low mercury wet deposition flux of 6 $\mu g/m^2$ yr; the experimental addition of 25 g (half a teaspoon) of various mercury isotopes over three years will increase this deposition by a factor of four to five, to a rate comparable to that currently observed in some parts of the United States Northeast and Florida.

After preliminary work in 1999-2000, the full scale experiments began in the summer of 2001 and will continue through 2003.

During the experiment, uplands, wetlands and the open water portion of the basin receive inputs of distinct and different mercury isotopes by means of various techniques (in a lake/water mixture from aircraft, sprayed mixture applications on land, dispersion in the lake waters from a small boat). After application, the three areas are continually sampled and analyzed by methodologies able to distinguish among the applied isotopes. As shown in Figure 24, this feature allows tracking of the movement of the mercury throughout the ecosystem to its arrival in fish, while sustaining identification of the transfer medium (upland, wetland, surface water) of the original applied mercury.

The information so gathered should illuminate several fundamental issues, among them the relationship between the amount of mercury in deposition and quantities of methylmercury in fish; the speed at which levels in fish would drop in response to a reduction in mercury deposition; and the impact of various environmental factors on the dimension and timing of this response. These issues are central to the current consideration of control strategies for the electrical generation and other mercury emitting sectors.

Entering its third full year, the program has generated extensive amounts of data, and the publication of outcomes in the scientific literature is underway and some papers have already been published. Integration and interpretation of the data is a continuous process and publication of several synthesis papers is anticipated. In addition, the nature of the Experimental Lakes Area allows for long-term monitoring of the fate of the added isotopic mercury, hopefully for several years beyond 2003.

Some preliminary observations are available. The mercury added directly to the lake has been detected in the zooplankton within four weeks of addition and also was determined both as total mercury and methylmercury in the sediments. It was apparent in fish by late July in the first year. Up to 14 percent of the methylmercury in fish was the isotopic form, with the balance being naturally occurring. Preliminary results indicate that no isotopes from the uplands or wetlands application were found in the lake.

The extent of the evasion or volatilization of the directly-applied mercury from the lake to the atmosphere was estimated at between 20 and 30 percent.

The research consortium maintains a website and meets every March to review progress to date and shape the work over the next season. Additions of isotopically-labeled mercury will have ceased by 2004, while the movement through the various compartments of the ecosystem, including fish, will continue to be tracked.

The IAQAB intends to continue to interact with members of the METAALICUS research team and to use the outcomes of this study as part of their further consideration of the mercury issue.

Fig.1

FIGURE 1
Geographical Distribution of the Estimated Contributions to the 1996 Atmospheric Deposition of Dioxin to Lake Superior
(Cohen *et al.*, 2002)

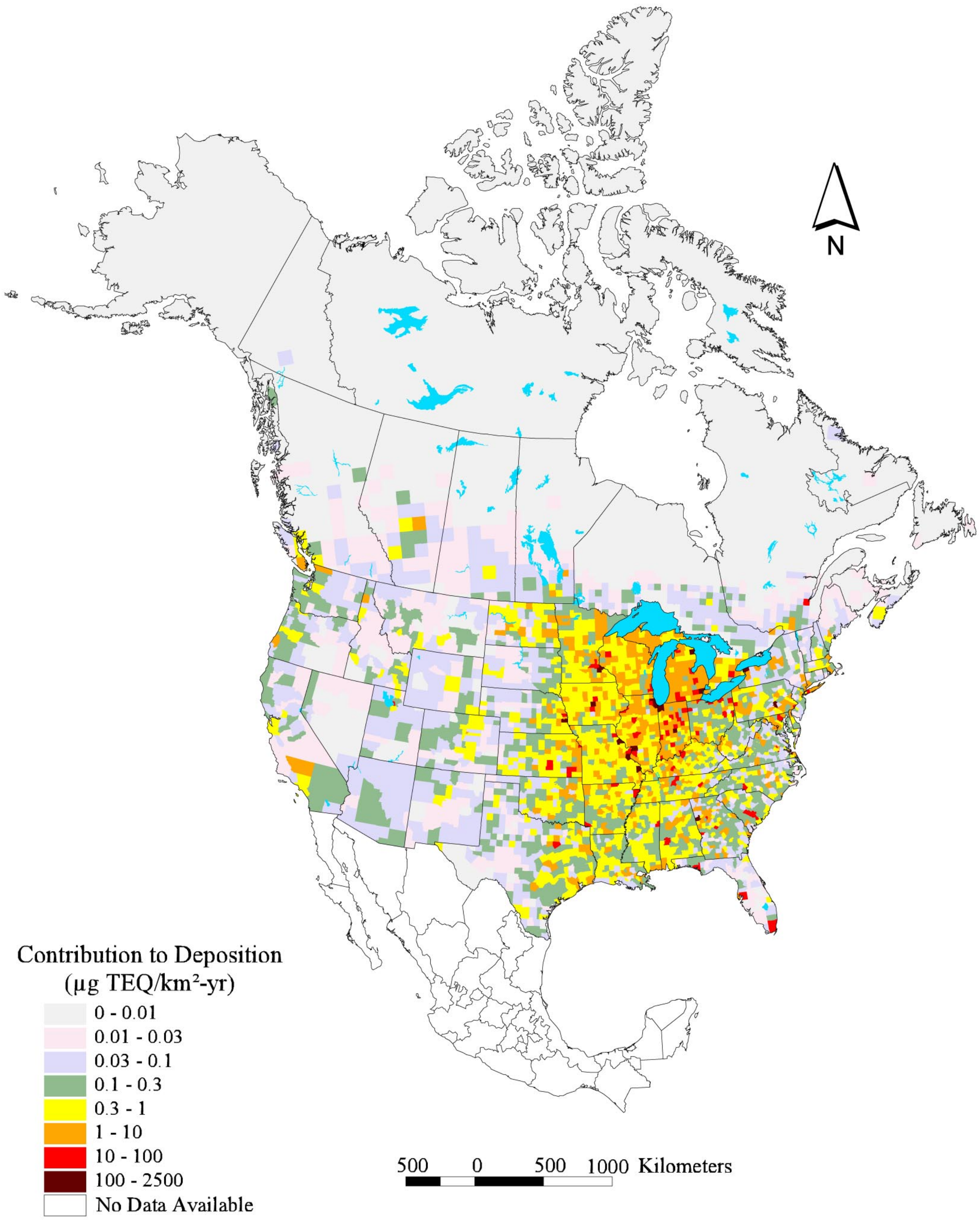

FIGURE 2
Global Emissions of Mercury

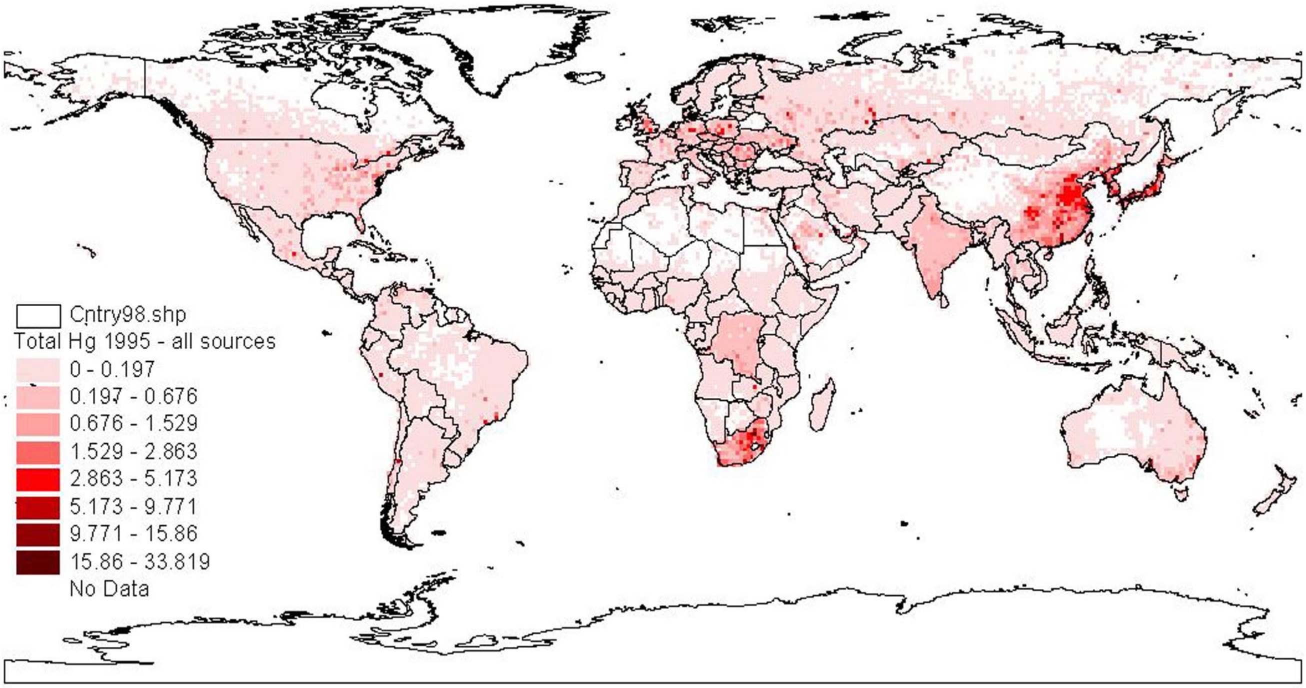

FIGURE 3
Trend in the Number of Advisories Issued for Various Pollutants

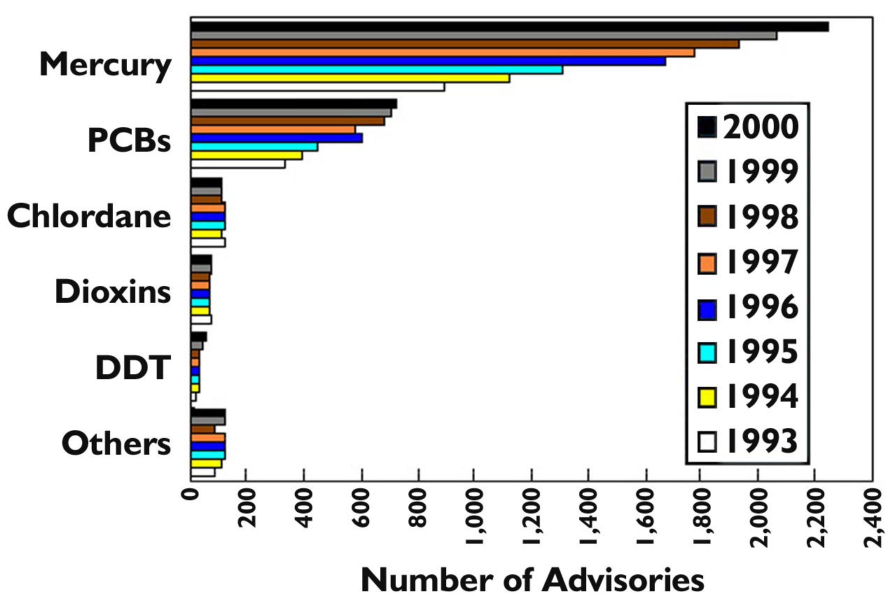

FIGURE 4
Atmospheric Fate Processes for Mercury

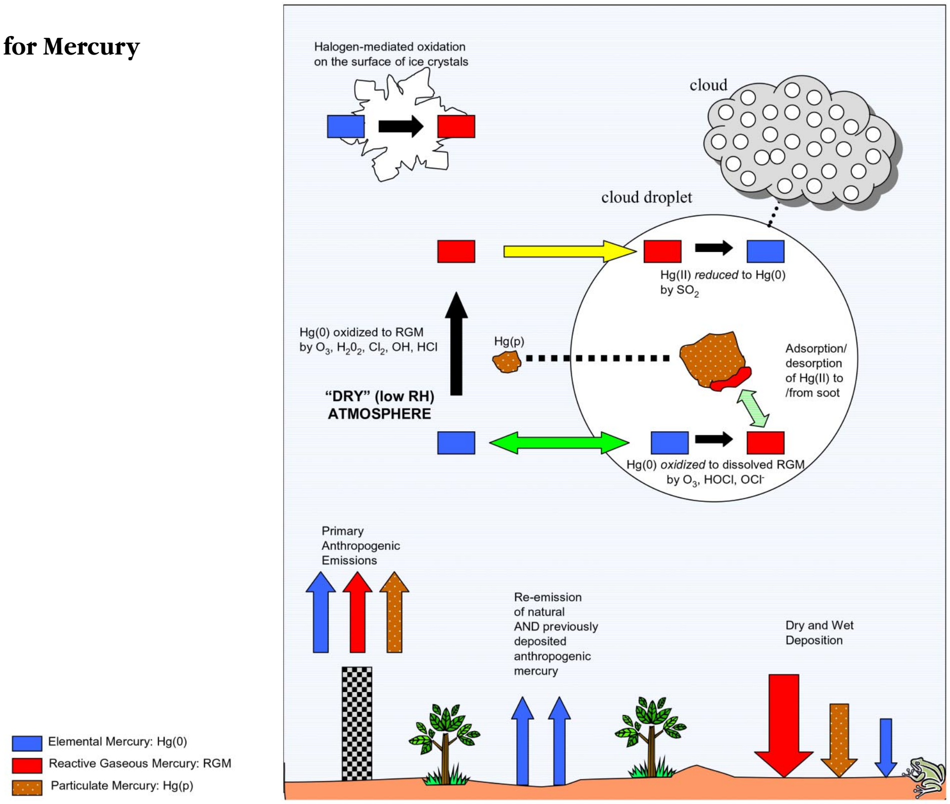

Fig.2
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FIGURE 5
Overall Transfer Coefficients for Mercury to Lake Superior during 1996 for Hg0, Hg(II) and Hg(p)

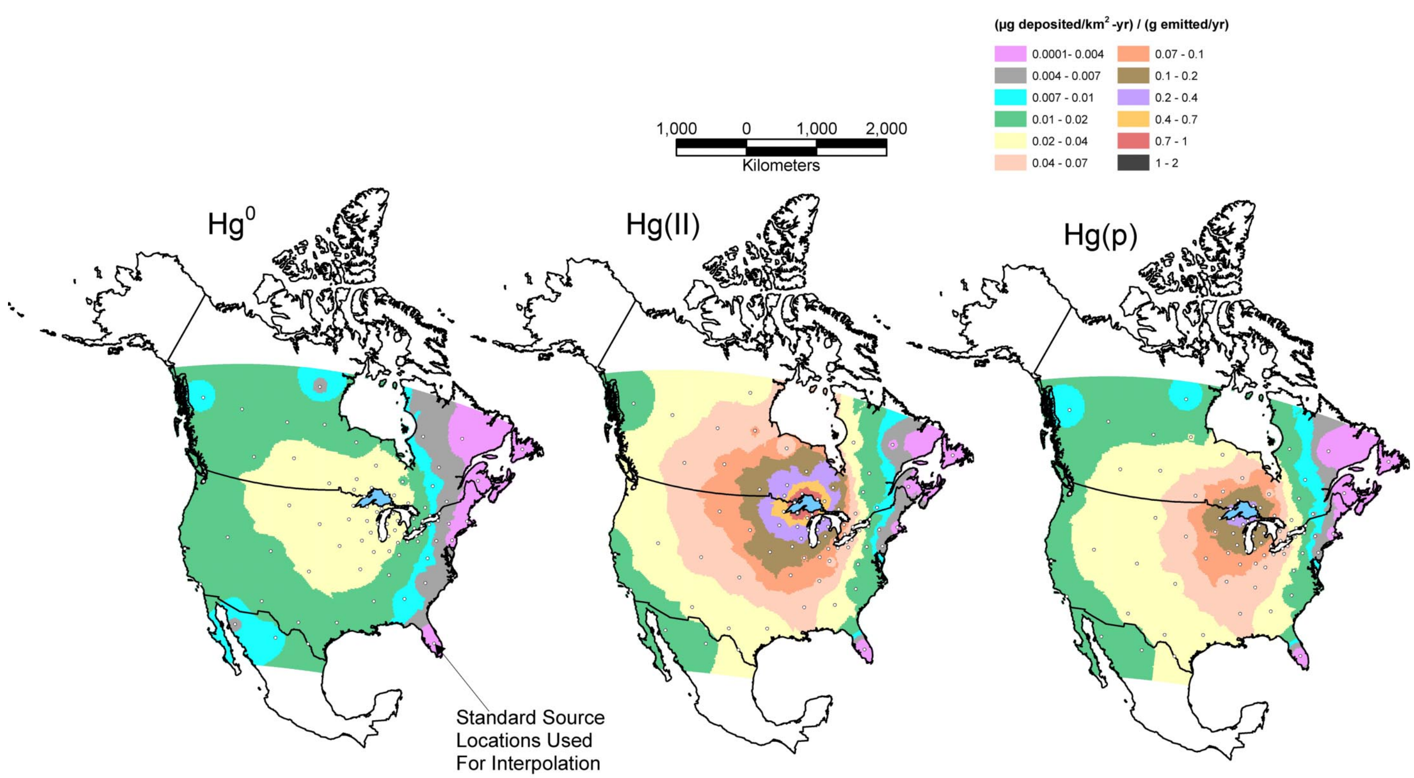

FIGURE 6
Overall Trasfer Coefficients for Mercury to Each of the Great Lakes during 1996 for an Emissions Profile Typical of Coal-fired Utility Boilers

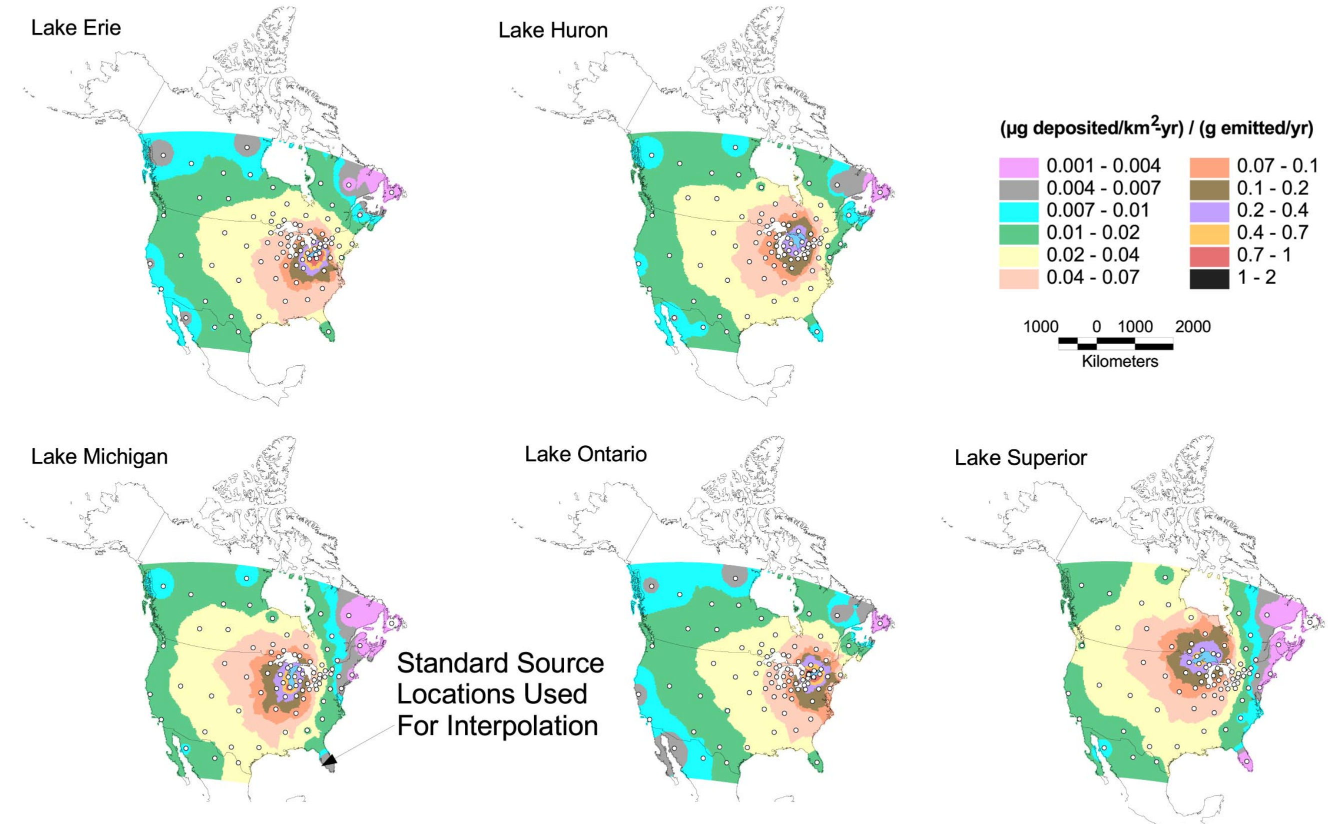

FIGURE 7
Geographic Distribution of Total Mercury Emissions to the Atmosphere from United States and Canadian Anthropogenic Sources

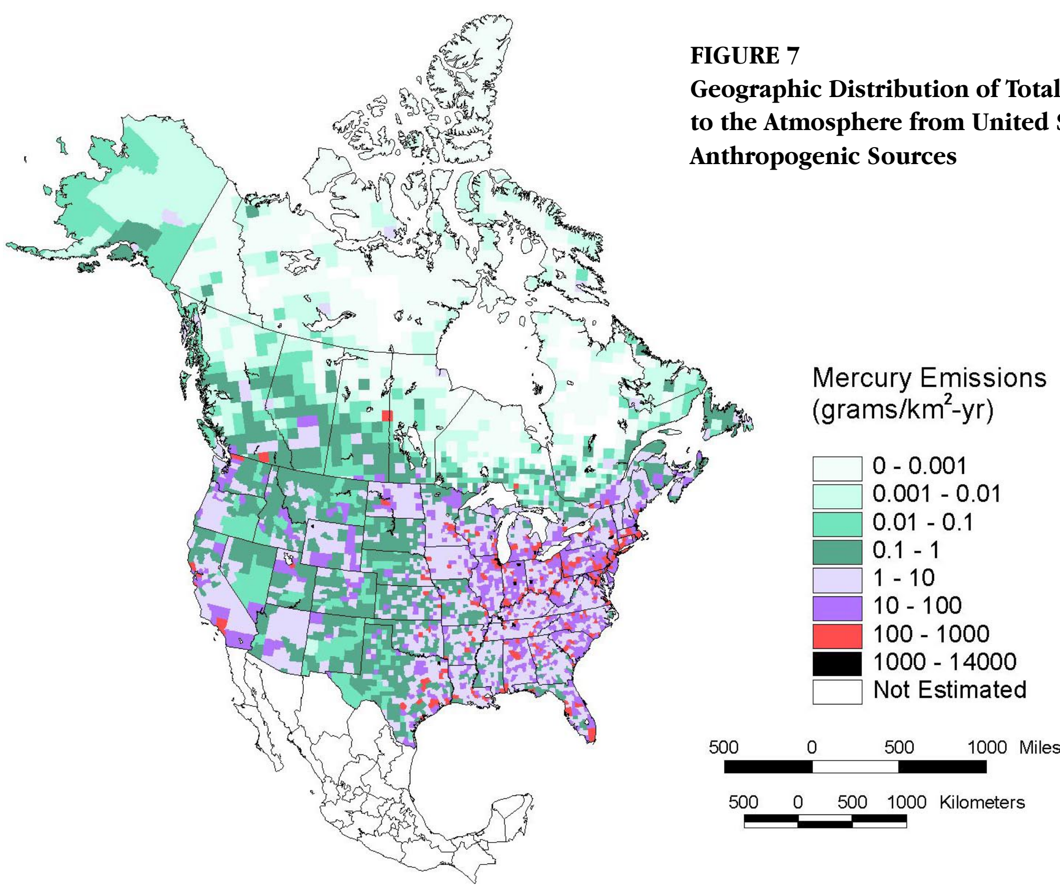

Fig.6
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9, 10

FIGURE 8
Annual Mercury Emissions from United States and Canadian Sources

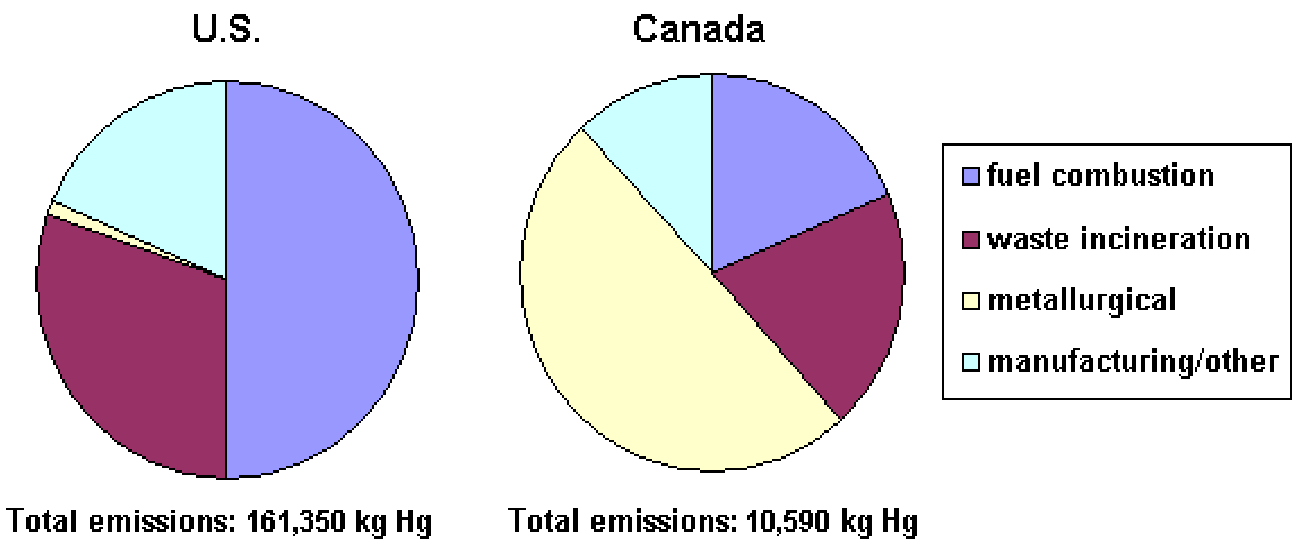


FIGURE 9
Annual *per capita* Mercury Emissions from United States and Canadian Sources (Aggregated Source Categories)

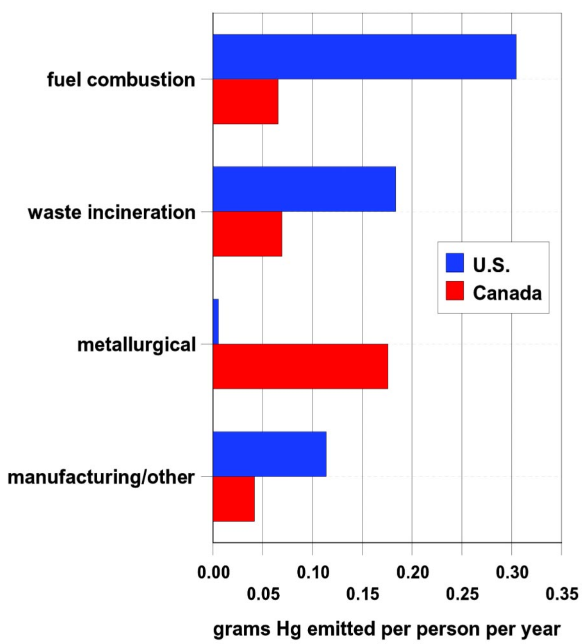


FIGURE 10
Annual per capita Mercury Emissions from United States and Canadian Sources (Detailed Source Categories)

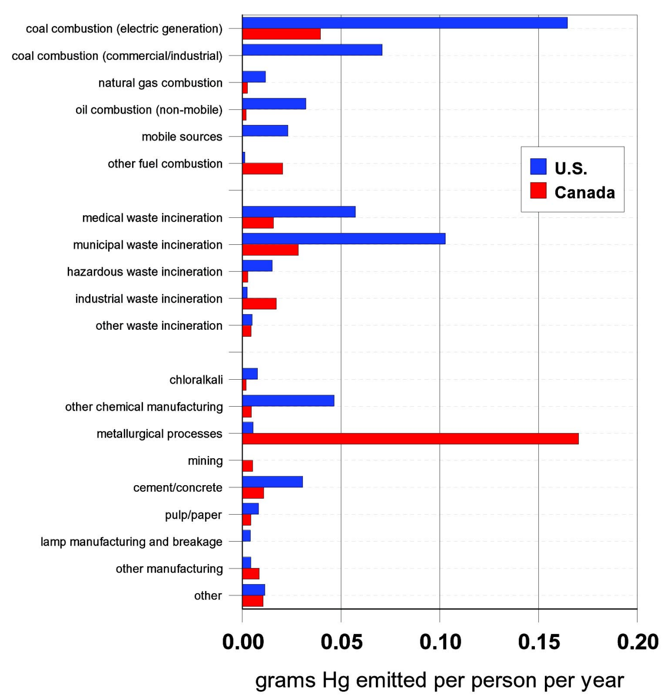


FIGURE 11
Speciation Profile of Mercury Emissions from United States and Canadian Anthrophgenic Sources

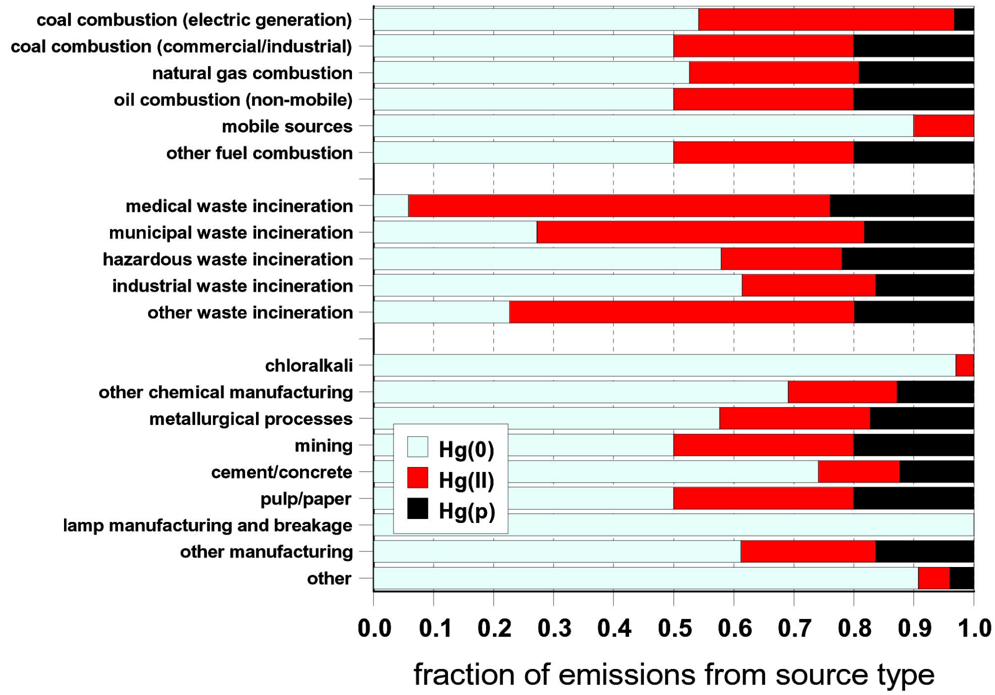


FIGURE 12
Speciated Annual Mercury Emissions from United States and Canadian Anthropgenic Sources

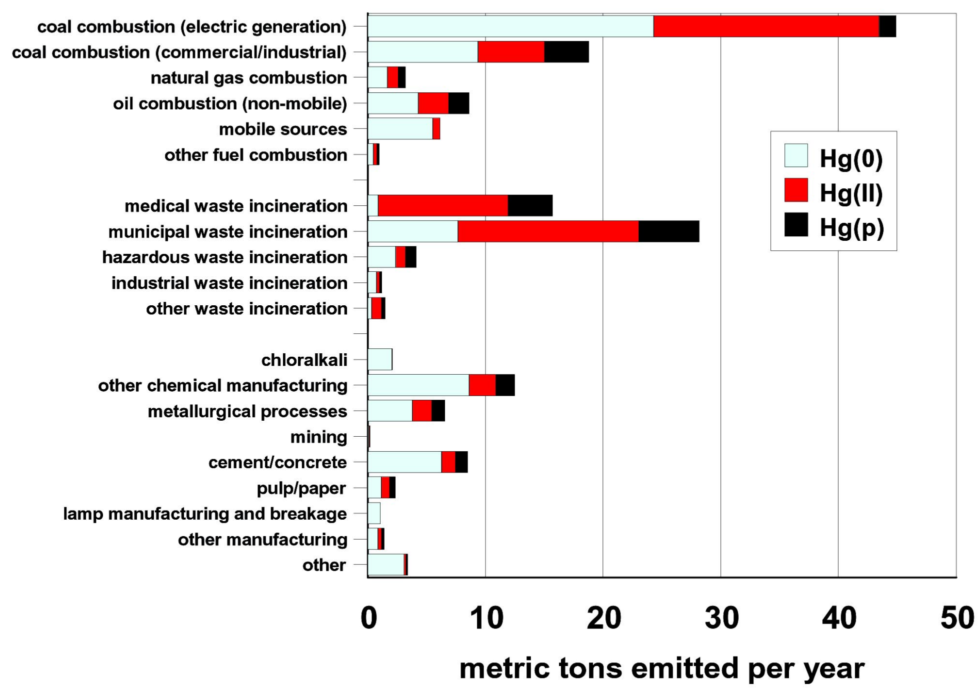


FIGURE 13
Model-estimated Annual Atmospheric Deposition amount to the Great Lakes arising from anthropogenic sources in the United States and Canada

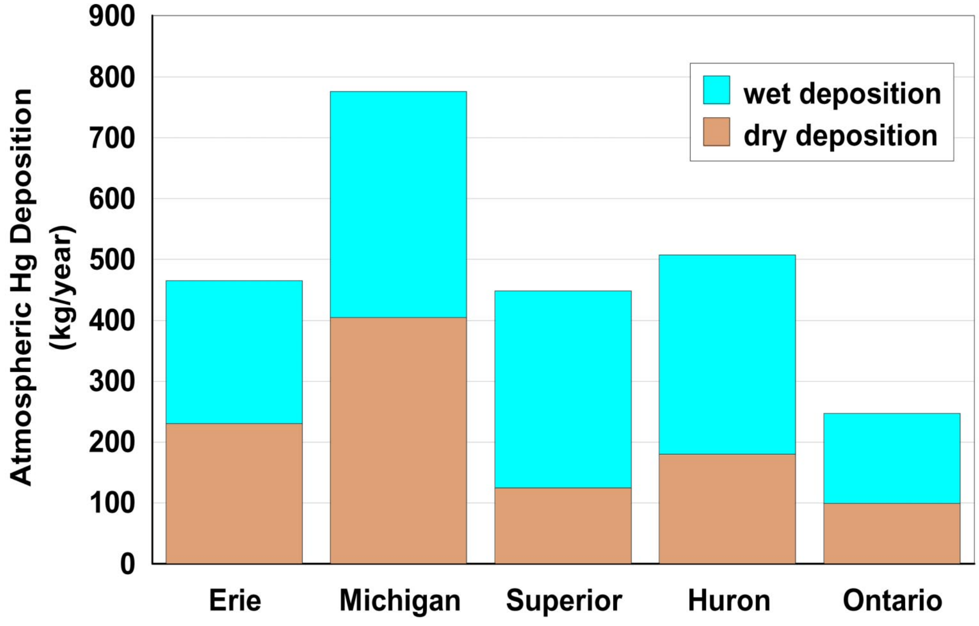


Fig.11 12, 13 14, 15

FIGURE 14
Model-estimated Annual Flux to the Great Lakes Arising from Anthropogenic Sources in the United States and Canada

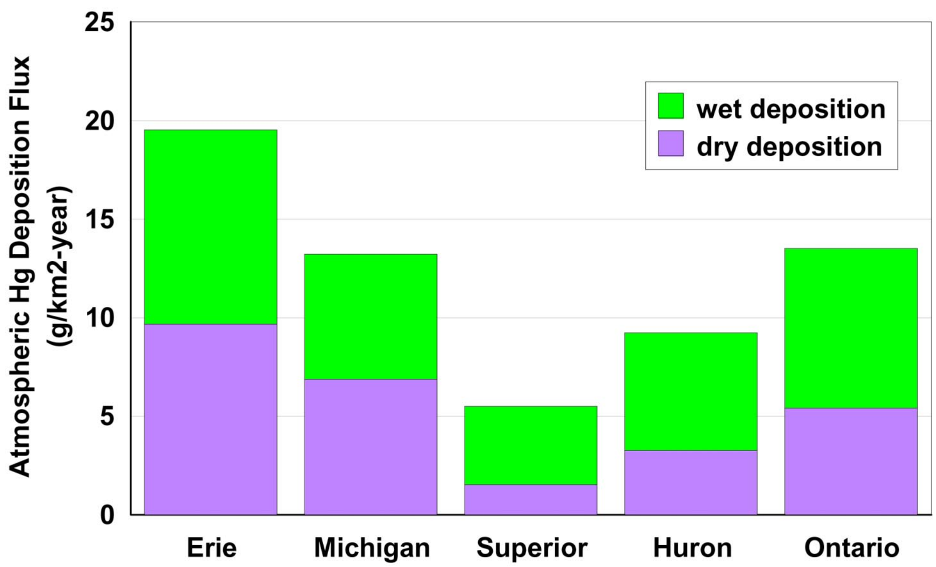


FIGURE 15
Geographic Distribution of Contributions to Atmospheric Deposition of Mercury to Lake Superior

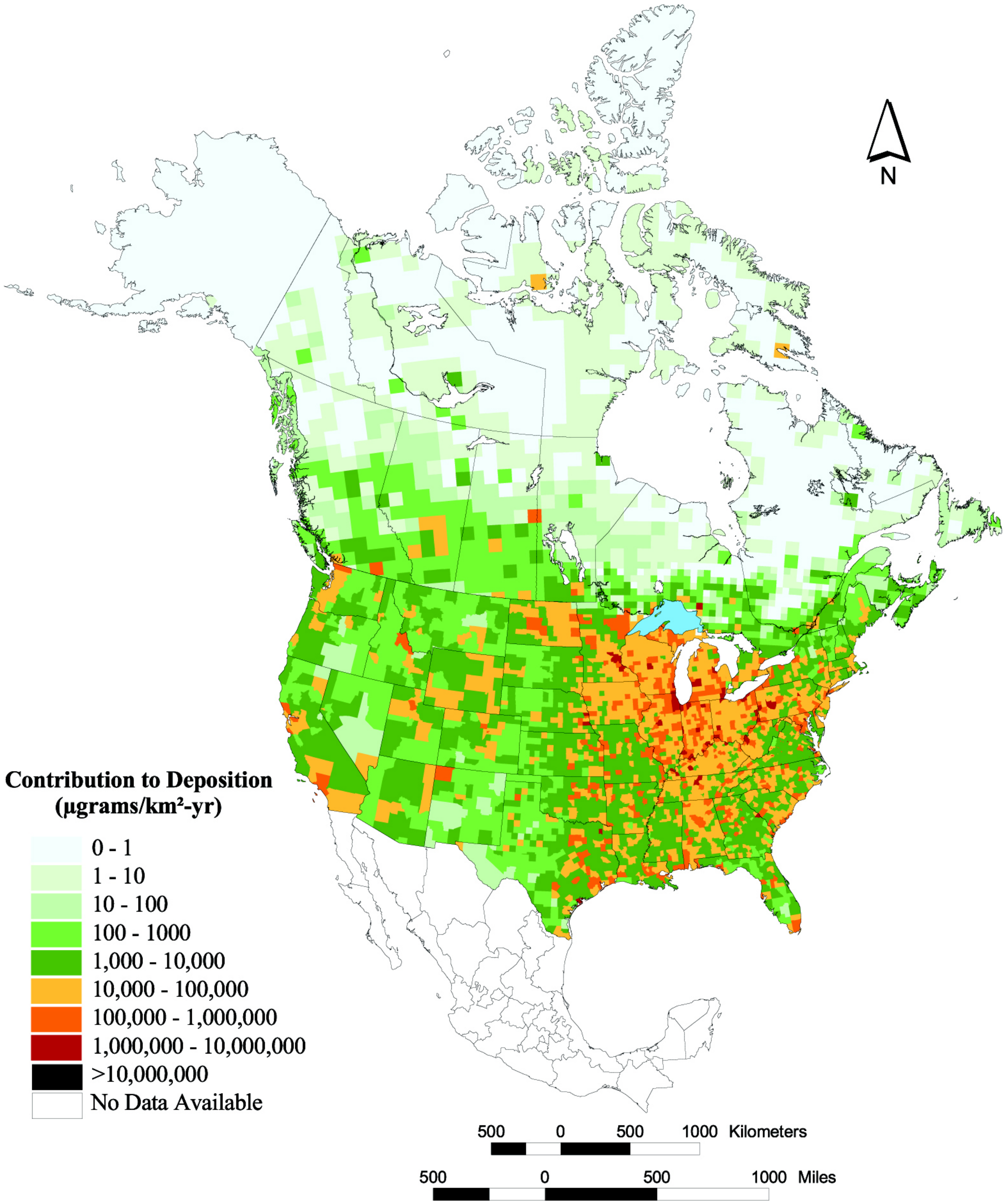


FIGURE 16
Geographic Distribution of Contributions to Atmospheric Deposition of Mercury to Lake Huron

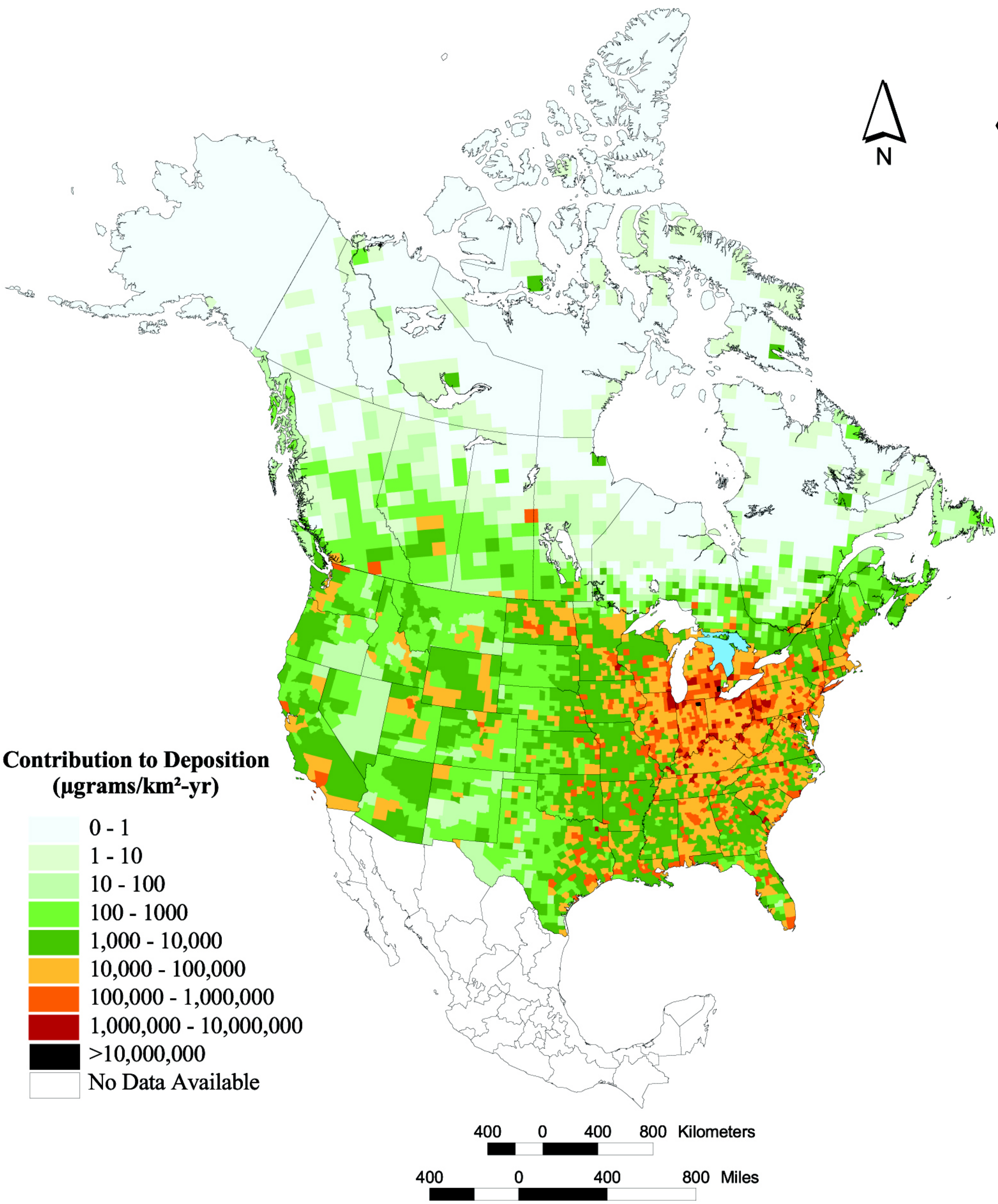


FIGURE 17
Geographic Distribution of Contributions to Atmospheric Deposition of Mercury to Lake Michigan

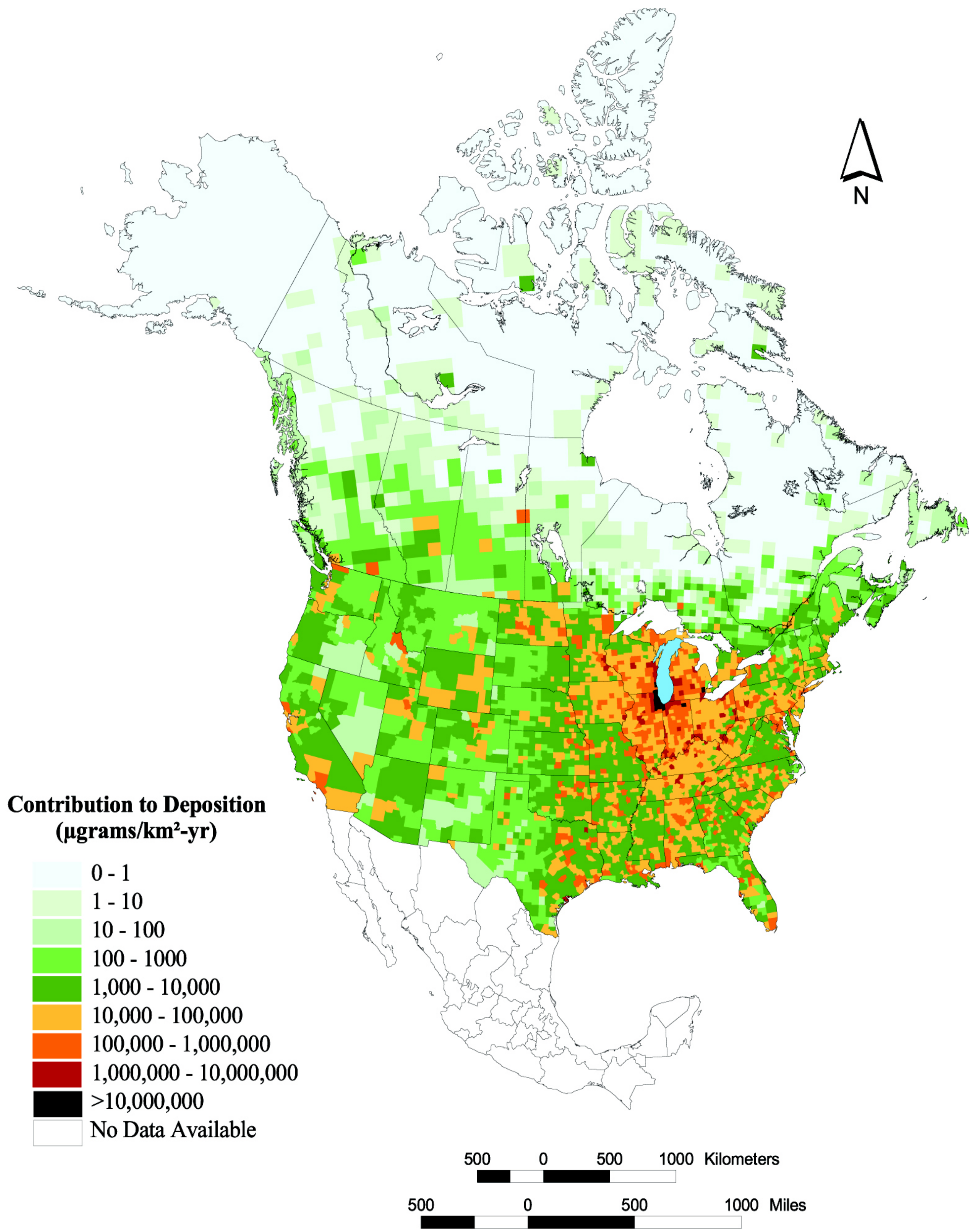


FIGURE 18
Geographic Distribution of Contributions to Atmospheric Deposition of Mercury to Lake Erie

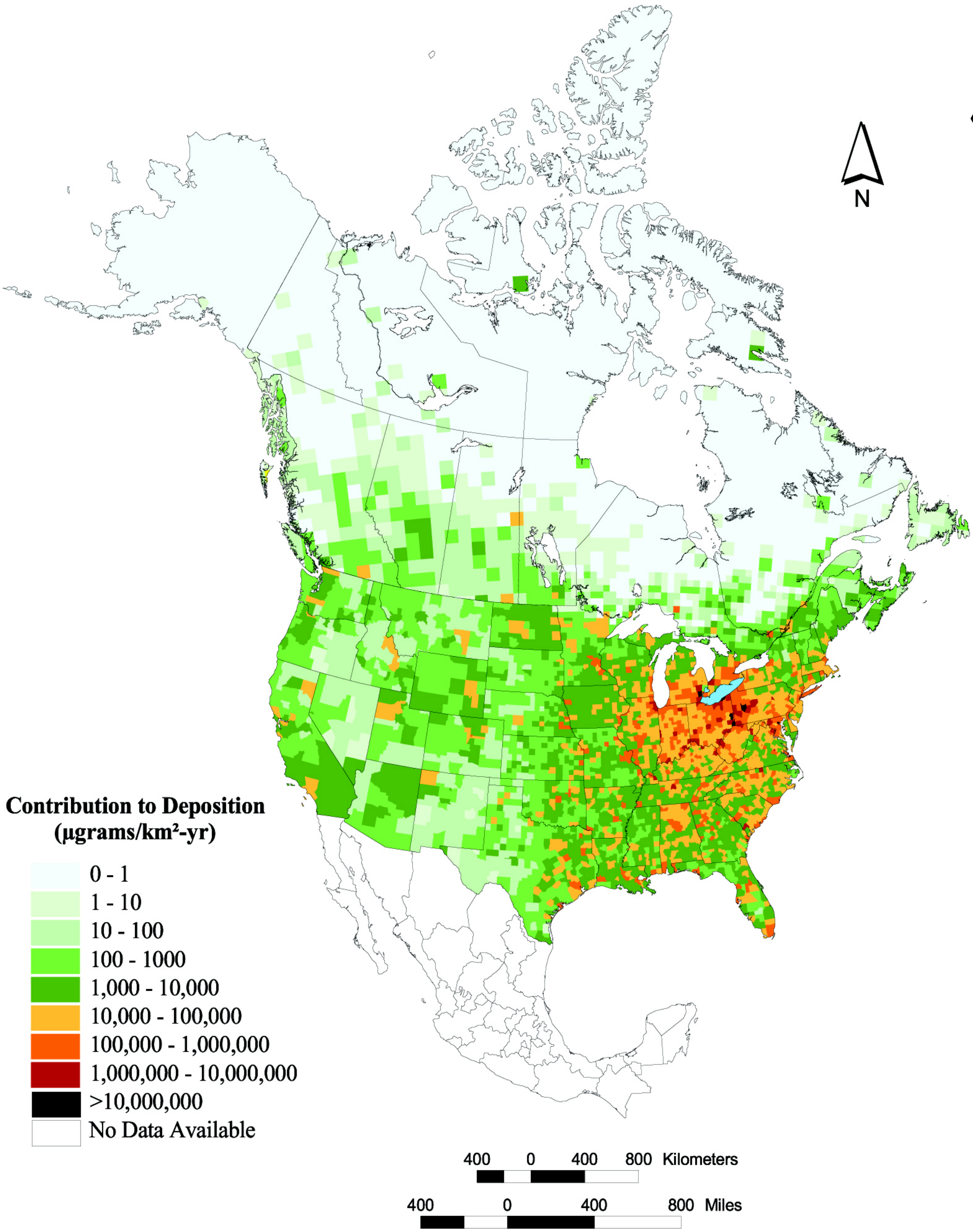


FIGURE 19
Geographic Distribution of Contributions to Atmospheric Deposition of Mercury to Lake Ontario

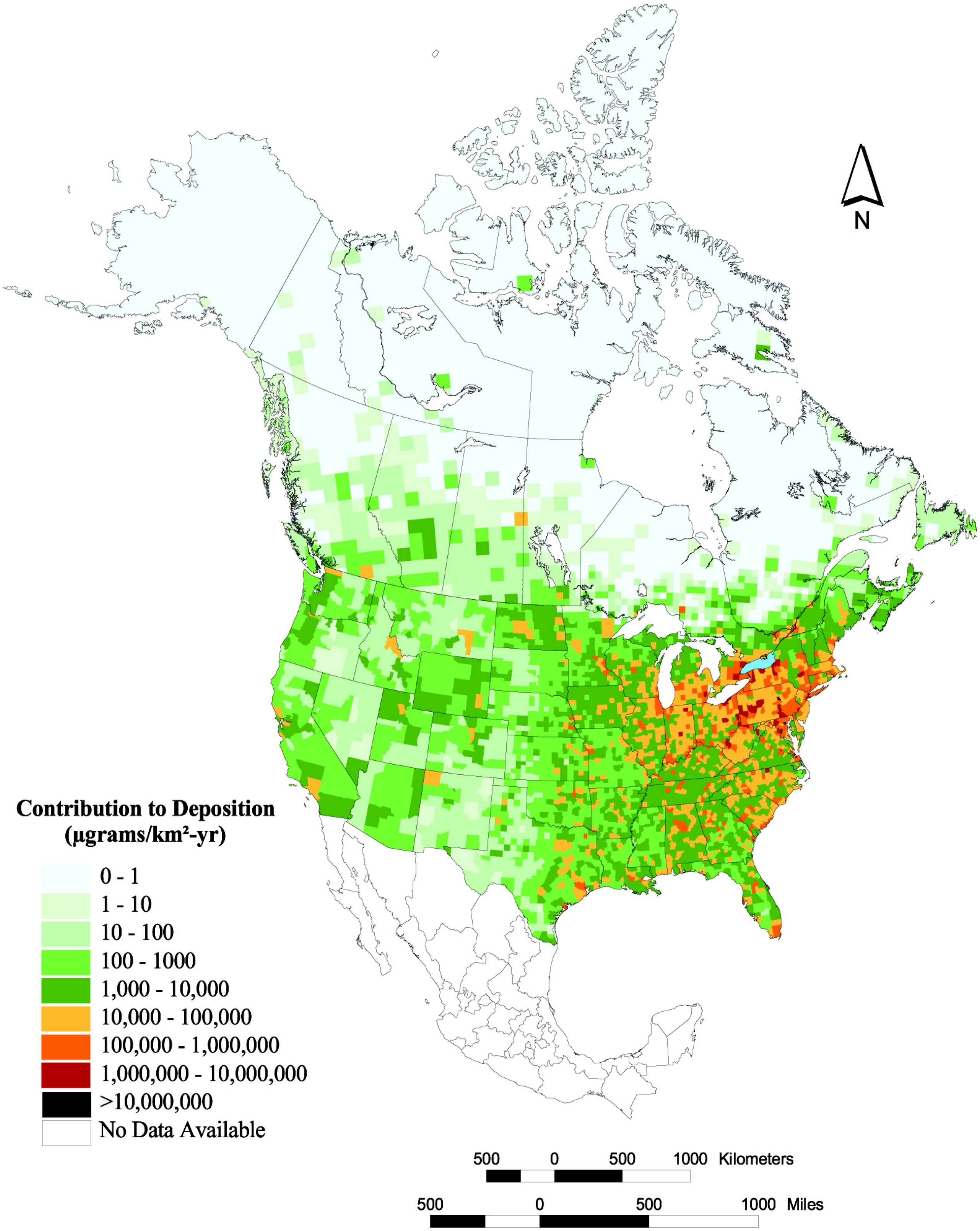


FIGURE 20
Percent of Total Estimated Emissions and Model-estimated Deposition of Mercury to the Great Lakes Contributed from Different Distance Ranges Away from Each Lake

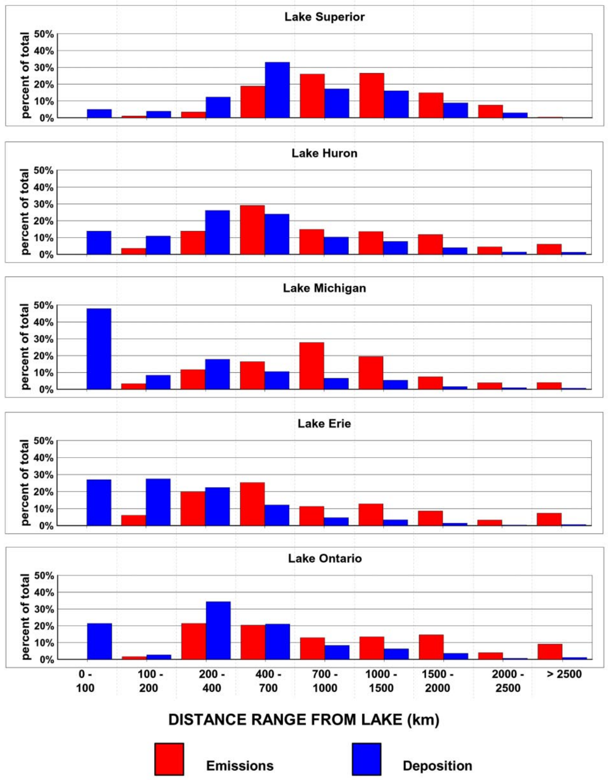


Fig.19
20, 21

FIGURE 21
Per-capita Mercury Contributions to the Great Lakes from United States and Canadian Sources

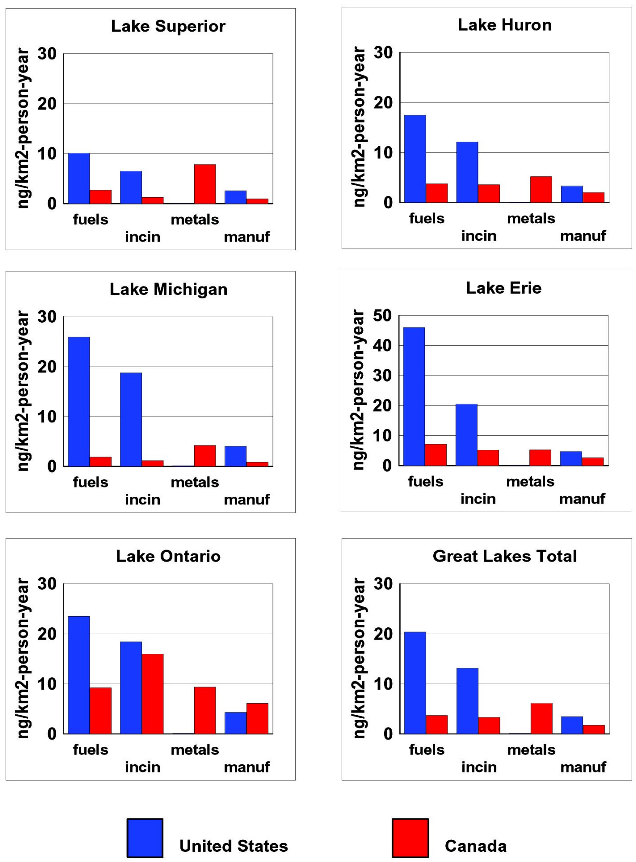


FIGURE 22
Comparison of Model-estimated Deposition to Lake Michigan (1996) with that estimated in the Lake Michigan Mass Balance Study (1994-1995)

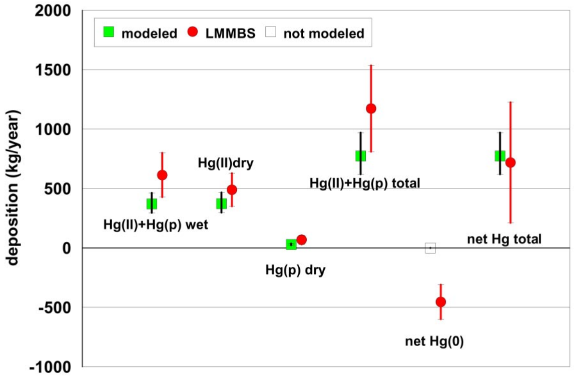
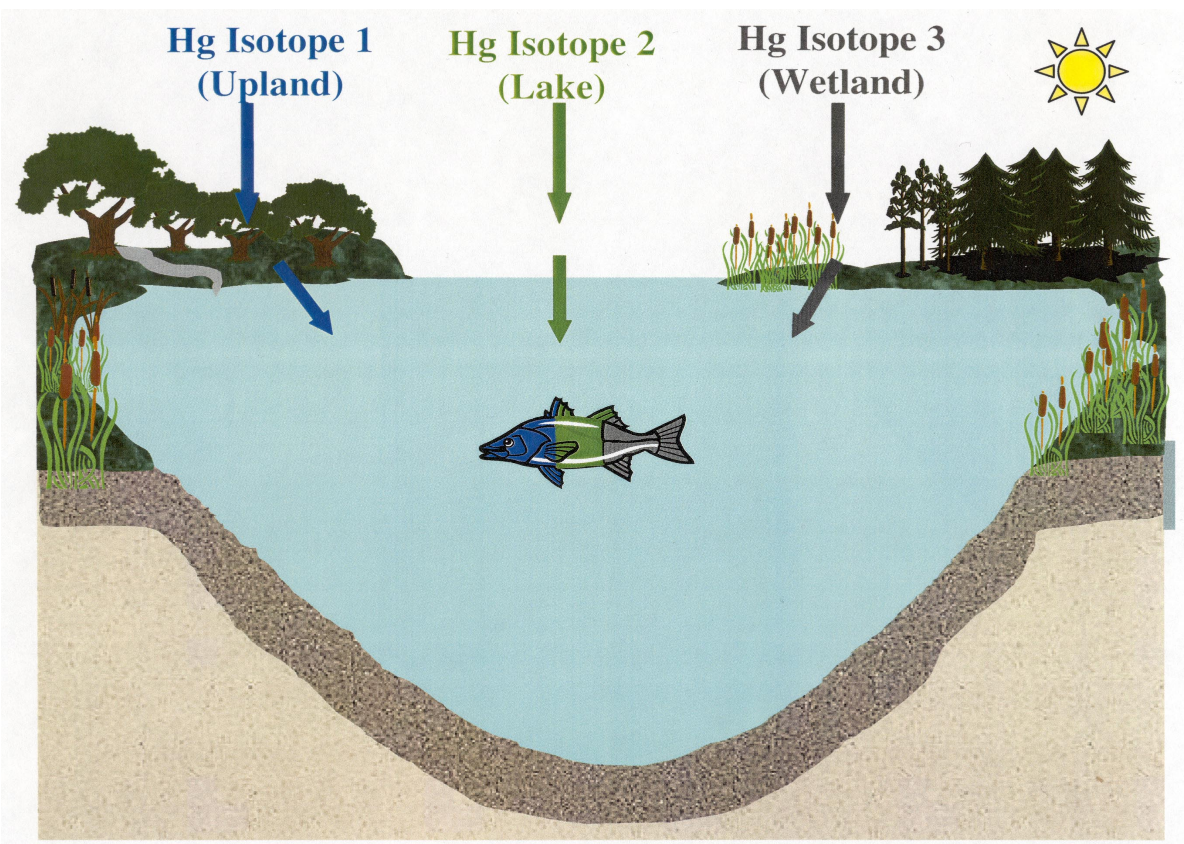


FIGURE 23
The Experimental Lakes Area Research Facility

FIGURE 24
Using Stable Isotopes to Measure Different Contributions to Fish Hg



Source: Reed Harris (Tetra Tech)

1.8 INTERNATIONAL AIR QUALITY ADVISORY BOARD MEMBERSHIP 2001-2003 (Sections 1.4 - 1.7)

Fig.22
23, 24
and 1.8

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1.9 REFERENCES (Sections 1.4 - 1.7)

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Priorities Report
Chapter 2

REMEDIAL ACTION PLANS AND LAKEWIDE MANAGEMENT PLANS

CHAPTER TWO Remedial Action Plans and Lakewide Management Plans

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Report of the Great Lakes Water Quality Board

Report of the Great Lakes Science Advisory Board

2.1 INTRODUCTION

During 2002, the IJC established a task force to provide expert advice on matters pertaining to Annex 2 of the *Great Lakes Water Quality Agreement* -- Remedial Action Plans and Lakewide Management Plans. The task force comprises a lead IJC commissioner from each country, up to three Great Lakes Water Quality Board members, two Great Lakes Science Advisory Board members, a member from the Council of Great Lakes Research Managers, the director of the IJC's Great Lakes Regional Office, and a provision additional individuals to be added as deemed necessary by the lead commissioners.

The Great Lakes Water Quality Board

To support the work of the IJC and its Task Force, the Great Lakes Water Quality Board reviewed U.S. and Canadian delisting guidelines and held consultations with Remedial Action Plan personnel at Hamilton Harbour and in the Detroit area. The WQB report is found in Sections 2.2 through 2.4.

The Great Lakes Science Advisory Board

The Great Lakes Science Advisory Board maintains watching briefs regarding new scientific knowledge and developments that may have implications for Great Lakes water quality. The SAB does not make recommendations on watching briefs, but they do provide an important opportunity for the SAB to alert the IJC and the Great Lakes Water Quality Board on a range of matters salient to the responsibilities under the *Great Lakes Water Quality Agreement*. The SAB's report on Annex 2 activities is found in Section 2.5.

2.2 REVIEW OF U.S. AND CANADIAN DELISTING GUIDELINES

2.2.1 Background

On December 6, 2001 the U.S. Policy Committee adopted the guidance, *Restoring United States Areas of Concern: Delisting Principles and Guidelines*. In response to a request from the U.S. Environmental Protection Agency, the IJC asked the WQB to review the document and corresponding Canadian materials.

Specifically, the IJC asked the WQB to review the approaches of each Party and provide comment on the:

- degree of consistency between the approaches of the United States and Canada; and
- degree of adherence or departure of both these approaches to the Agreement, particularly Annex 2.

The WQB based its review on three documents:

- *Restoring United States Areas of Concern: Delisting Principles and Guidelines*. Adopted by the United States Policy Committee, December 6, 2001. Available on the web at http://www.epa.gov/glnpo/aoc/delist.html . (U.S. Guidance)
- *Recognizing Areas of Concern That Have Completed RAP Implementation*. Approved January 1999 by the Canada Ontario Agreement Review Committee. (COA Guidance)
- *A Guide to Producers, Users and Reviewers of Stage 2 and Stage 3 Reports*. Excerpts from an Ontario manual designed for those who write and review Stage 2 and Stage 3 Remedial Action Plan documents. (Ontario Guidance)

The WQB presented the following findings and advice to the IJC on February 6, 2002. Also presented below is the IJC's response to this advice.

2.2.2 Findings of the Great Lakes Water Quality Board

Consistency between the Approaches of the United States and Canada. The WQB finds that the approaches taken by Canada and the United States are reasonably consistent and functionally equivalent.

Adherence or Departure of both Approaches to the Agreement, particularly Annex 2. The WQB finds that both approaches are not inconsistent with the requirements of the Agreement.

2.2.3 Discussion

Principles

The U.S. and the Ontario Guidance both articulate sound principles for delisting beneficial use impairments. However, the Ontario Guidance states that "Achievement of delisting targets can also be judged against the inherent philosophies and principles of RAPs (i.e. sustainability, ecosystem approach, pollution prevention, public involvement)." The WQB believes that the focus of the delisting principles should be specifically related to the use impairments in Annex 2 and not to such additional factors as sustainability or the ecosystem approach which, while important, add an unnecessary degree of complexity. The Parties should focus on fulfilling their Annex 2 commitments to restore Areas of Concern.

Scope and Focus

The U.S. Guidance acknowledges "the question of how to accelerate the Remedial Action Plan process and restoring beneficial uses." The Canadian and the U.S. documents focus on a delisting process but, without active progress, development of delisting criteria is an academic exercise. The WQB expresses its desire for re-energizing the Remedial Action Plan process, leading to action that will restore beneficial uses in Areas of Concern.

Although the U.S. and the Canadian documents focus on delisting, the WQB recognizes that they were prepared for somewhat different purposes. The U.S. Guidance focuses on a process that leads to ecosystem response and subsequent delisting of an Areas of Concern, with allowance for designating an Areas of Concern as being in a recovery stage as an intermediate step in that process.

The two Canadian documents focus on a process through which, upon completion of implementation of remedial actions, an Area of Concern can be reclassified as an Area of Recovery, providing a basis to celebrate when implementation is complete. The end point in the Canadian documents is not necessarily delisting an impaired use or an Area of Concern. Canada should articulate a delisting process similar to that presented in the U.S. Guidance, including the roles and responsibilities of federal and provincial officials and ministries.

Agreement Requirements and Locally Defined Goals

The Canadian and U.S. documents provide for local flexibility, and the U.S. Guidance specifically notes that it is not prescriptive. The documents discuss achievement of locally defined goals that are linked to local sources, as opposed to sources outside the Area of Concern. When such locally defined goals are met and local sources that contribute to the impairment are controlled to the extent feasible, then there are grounds for consideration of delisting.

The WQB is concerned that some wording in the documents is open to interpretation. For example, locally defined goals could be interpreted as less than full restoration of beneficial uses, and that less than full achievement of the purpose of the *Great Lakes Water Quality Agreement* is acceptable. For example, the U.S. Guidance states that "It is recognized and permissible to determine that a beneficial use cannot be fully restored" and "delisting occurs when locally derived targets are met."

Such decisions can be judgmental. For example, both the U.S. Guidance and the COA Guidance present a criterion that Remedial Action Plan implementation is complete when "all reasonable and practical implementation has occurred." The U.S. Guidance continues, such decisions are reached when "the RAP Implementation Group and the local public are satisfied with current conditions and local recovery."

Conversely, the locally defined goals and requirements for public satisfaction may be more stringent than the Annex 2 requirements.

The WQB seeks reassurance that the purpose of the Agreement will not be compromised by the material presented in the U.S. and the Ontario Guidance. The documents should contain clear statements to the effect that locally derived delisting targets are at least as stringent as the Agreement requirements and that satisfaction with the agreed-upon local end conditions do not compromise the Agreement purpose.

The WQB seeks reassurance that the purpose of the Agreement will not be compromised by the material presented in the U.S. and the Ontario Guidance. The documents should contain clear statements to the effect that locally derived delisting targets are at least as stringent as the Agreement requirements and that satisfaction with the agreed-upon local end conditions do not compromise the Agreement purpose. Such clarification and consistency will help ensure a common understanding and avoid potential future interpretation problems.

Binational Guidance and Public Reporting

The Parties may wish to consider development of a single binational guidance document, applicable to all Areas of Concern. They may also wish to consider preparation, when appropriate, of separate documents, designed for public release, that clearly describe the process, criteria, and rationale for delisting a specific impaired beneficial use in an Area of Concern or for concluding when a specific Area of Concern warrants redesignation as an Area of Recovery / recovery stage.

Surveillance and Monitoring

It is not clear in either the Canadian or the U.S. documents that surveillance and monitoring have been undertaken to confirm that beneficial uses have been restored, as called for in Remedial Action Plan Stage 3, and delisting can be substantiated.

Other Considerations

Unlike the U.S. Guidance, the Canadian documents do not discuss a process for binational Areas of Concern.

The U.S. Guidance allows for the delisting of sub-watersheds before delisting an entire Area of Concern. Canada should consider such an approach.

The U.S. Guidance defines the IJC role through consultation with the director of the Great Lakes Regional Office. Consultation with Commissioners may be more appropriate.

The Canadian and U.S. documents would benefit from editing to improve clarity, ensure internal consistency, and correct errors of spelling, fact, and quotations.

2.2.4 Advice of the International Joint Commission

In response to the WQB's advice, by letters dated March 19, 2002, the IJC sent the following observations and advice to the Parties and to Ontario.

Beneficial Uses

"According to Annex 2 of the Agreement, delisting follows the restoration of beneficial uses. The U.S. document identifies that in order to delist an AOC, restoration of beneficial uses is required. While it is implicit in the documents reviewed, the Commission recommends that the Canadian documents explicitly state that in order to delist an Area of Concern the end point is the restoration of beneficial uses. The Commission is aware, however, that this is the policy of Canada and Ontario and that the two parties have consulted substantively on this matter.

"The Canadian documents describe a process through which, upon completion of implementation of remedial actions, an Area of Concern can be recognized as an area of recovery. Consideration of other factors such as sustainability or locally defined goals is acceptable provided they are in addition to and do not replace the requirements of the Agreement. The Commission's 1991 Delisting Criteria ... provide guidance for consideration for each beneficial use.

Documentation

"The Commission is of the opinion that all the relevant documents be publicly available. This is the case with the ... U.S. document. The Commission recommends that the policies of Canada and Ontario be made available in a single public document, and if such a document does in fact exist, that the Commission be provided with such along with information on how the public can access the document.

Clarity

"The WQB noted that some of the wording in the Canadian and U.S. documents is open to interpretation. For example, achieving "locally defined goals" could imply that achieving something less than the purpose and objectives of the Agreement is fully acceptable. While there may be cases when incomplete restoration of beneficial uses is justifiable, the Commission seeks reassurance that the Agreement purpose not be compromised by any of the material presented in the guidance documents, and recommends that language in delisting guidance documents be made explicit as to intent.

Surveillance and Monitoring

"The Commission notes that the documents clearly state that monitoring is required to determine that beneficial uses have been restored and then subsequently maintained and seeks assurance that such monitoring is necessary and sufficient to measure recovery of beneficial uses.

"The Commission anticipates that the Parties' efforts to develop guidance on the delisting process will encourage increased resources and the coordination of efforts in each AOC and will result in the more timely achievement of the goals of the Agreement."

Reporting

"The Agreement states in Annex 2 Section 4 (d) that Remedial Action Plans shall be submitted to the Commission for review and comment at three stages, one of which is when monitoring indicates that identified beneficial uses have been restored. The Commission expects that Stage 3 Reports will be included in any delisting process unless the Parties formally revise the Agreement.

Consultation with the Commission

"Given the importance of Annex 2 and the RAP restoration process to achieving the Agreement's purpose and the value of ongoing communication, the Commission believes that informal consultation with the Director of the Great Lakes Regional Office followed by formal consultation with Commissioners is both desirable and appropriate.

"The Commission is pleased that the Parties are looking ahead to delisting some of the Areas of Concern, and that they are attempting to be transparent in describing their policies and procedures. To further this goal, the Parties may wish to consider development of a single binational guidance document applicable to all AOCs which also addresses the organizational differences in the two countries. At the least, Canada and Ontario should revise and disseminate a single comprehensive guidance document.

"The Commission anticipates that the Parties' efforts to develop guidance on the delisting process will encourage increased resources and the coordination of efforts in each AOC and will result in the more timely achievement of the goals of the Agreement."

2.3 HAMILTON HARBOUR REMEDIAL ACTION PLAN CONSULTATION

2.3.1 Background

The WQB held its 146th meeting in Hamilton, Ontario on June 26-27, 2002. The WQB took advantage of the opportunity to consult with personnel involved with the Hamilton Harbour Remedial Action Plan. The intent was to learn how successes to date had been achieved, become better informed about today's key issues, and ascertain how the WQB could help advance restoration and protection of Hamilton Harbour.

In addition to a tour of the harbour courtesy of the Hamilton Port Authority, the WQB received four informative presentations and accompanying background material:

- *RAP State of the Harbour Update*. John Hall, Environment Canada, Remedial Action Plan Coordinator.
- *Randle Reef Remediation Project*. John Shaw, Environment Canada.
- *Hamilton Wastewater Treatment Plant Upgrades.* Lou di Gironimo, City of Hamilton.
- *Report Card 2002 and Comments*. Marilyn Baxter, Bay Area Restoration Council.

The WQB also had the opportunity to engage in informal and candid discussions.

2.3.2 Findings of the Great Lakes Water Quality Board

The WQB provided the following findings and advice to the IJC on August 8, 2002. Also presented below is the IJC's response to the WQB's advice.

The key points emerging from the consultation were the following.

Significant progress has been made in restoring Hamilton Harbour and its watershed. For example, since 1990:

- Public access to the harbour shoreline has increased from five to 21 percent.
- 340 hectares of new habitat has been established, and 170 hectares of aquatic vegetation has returned to the harbour.

In addition, because of the improvement in water quality, people can safely swim in the harbour for the first time in 50 years.

The Remedial Action Plan has achieved successes because of strong local leadership to build community capacity and foster ownership of both the environmental problems and their resolution. The Bay Area Restoration Council and the Bay Area Implementation Team provide effective means for local stakeholder engagement, leadership, and accountability for planning and implementation of programs and measures to restore and protect Hamilton Harbour. The Bay Area Restoration Council is the community group that promotes the Remedial Action Plan, and the Bay Area Implementation Team is comprised of implementers, who work with the Remedial Action Plan coordinator.

An additional result of local stakeholder involvement is sustained community effort and dedication to the Remedial Action Plan.

The community is currently engaged in updating the 1992 Remedial Action Plan Stage 2 report and in revising delisting targets, with the intention of setting more ambitious targets.

Wastewater treatment system infrastructure improvements are vital for restoration of the harbour. Infrastructure is the responsibility of the City of Hamilton and the Region of Halton. These municipalities are actively engaged in the Remedial Action Plan process and, to meet Remedial Action Plan targets, have committed to upgrading the performance of their wastewater treatment plants to exceed provincial standards.

Federal support for the position of Remedial Action Plan coordinator has contributed to the achievement of success.

Notwithstanding significant accomplishments to date, much remains to be done. Continued federal and provincial support, including provision of scientific and technical expertise, is necessary to keep the Remedial Action Plan process moving forward and to ensure that Remedial Action Plan restoration goals and targets are met by 2015.

Federal and provincial funding is essential to defray the costs associated with upgrading and expanding the infrastructure for wastewater and of sediment cleanup. Specifically:

- An estimated $478 million is required over the next 10 to 12 years to upgrade the City of Hamilton's wastewater and combined sewer systems, in order to meet Remedial Action Plan delisting criteria.
- An estimated $18 to 25 million is required for the Randle Reef sediment remediation project.

Success in these programs will help ensure that the ambitious vision established by local stakeholders is achieved.

2.3.3 Advice and Recommendations of the Great Lakes Water Quality Board

The WQB recognizes the importance of community involvement in restoring Hamilton Harbour.

The WQB recommends the following to the IJC:

- **Recommend that the governments of Canada and Ontario continue to provide administrative and project support for the Hamilton Harbour Remedial Action Plan.**

The cost of improvements to water and wastewater infrastructure is beyond the capability of the municipal tax base. Resources from all levels of government are required in order to meet Hamilton Remedial Action Plan goals and targets.

The WQB recommends the following to the IJC:

- **Recommend that the governments of Canada and Ontario commit to a tripartite funding partnership with the city of Hamilton to finance upgrades to wastewater infrastructure.**

- **Recommend that the governments of Canada and Ontario commit to a funding partnership for the expeditious cleanup of contaminated sediment.**

The WQB requested IJC approval to share its advice with the Hamilton Harbour Remedial Action Plan Coordinator and other Remedial Action Plan personnel.

2.3.4 Advice of the International Joint Commission

In response to the WQB's advice, on September 19, 2002 the IJC sent letters to the Parties and to Ontario. The IJC provided the following observations and three recommendations.

"The Water Quality Board was particularly impressed with the significant progress which has been made in restoring Hamilton Harbour, ranging from increased public access to the shoreline, to improved vegetation and water quality. People can safely swim in the harbour for the first time in 50 years...

"Much of the success to date is attributable to the strong local leadership which has built community capacity and fostered ownership of both the environmental problems and their resolution. The Bay Area Restoration Council (the community group) and the Bay Area Implementation Team (the implementors) provide effective means for local stakeholder engagement, leadership, and accountability for planning and implementation of programs and measures to restore and protect Hamilton Harbour. Key to the achievements is the federal support for the position of a RAP coordinator.

"In 1999 the Commission conducted a Status Assessment of the Hamilton Harbour Area of Concern. It is encouraging to note that progress is continuing, support for the RAP is being maintained, and that agreement has been reached with the community regarding the remediation approach for Randle Reef.

"Meeting RAP delisting criteria by 2015 will require a considerable amount of work and funding. An estimated $478 million is required over the next 10 to 12 years to upgrade the City of Hamilton's wastewater and combined sewer systems. A further $18 to 25 million is required for the proposed Randle Reef sediment remediation project. These projects are clearly beyond local capacity and will require assistance from a number of parties. Water rates have already been increased considerably by the local council to help defray some of the upgrades.

"After considering the advice of the Water Quality Board the Commission is recommending the following:

- **The Governments of Canada and Ontario continue to provide funding for the RAP coordinator, projects and general administration as well as scientific and technical expertise.**

- **The Governments of Canada and Ontario commit to a partnership with the City of Hamilton to finance upgrades to wastewater infrastructure.**

- **The Governments of Canada and Ontario proceed with the technical assessment of the remediation of the contaminated sediment in the area of Randle Reef and create a partnership for the necessary funding to implement the project.**

"Hamilton Harbour is a success story in progress. The Commission encourages all levels of government and the private sector to support the implementation of the RAP and provide the assistance needed to build on its past successes, to achieve its delisting targets and to be an example and inspiration to other Areas of Concern."

2.4.1 Background

The Water Quality Board held its 149th meeting in Romulus, Michigan on March 6-7, 2003. The WQB took advantage of the opportunity to consult with personnel involved with the Rouge River, Clinton River and Detroit River Remedial Action Plans. The intent was to learn how successes to date had been achieved, today's key issues, factors that inhibit progress, and how the WQB could help advance restoration and protection of these three rivers. The WQB also was interested in connections among the three Areas of Concern.

In addition to a tour of selected remediation sites, courtesy of the Wayne County Department of Environment and Ford Motor Company, the WQB received informative presentations and accompanying background material:

- *Successes and Challenges in the Rouge River Area of Concern*. Kurt Heise, Chair, Remedial Action Plan Advisory Council and Director, Wayne County Department of Environment; and Joe Rathbun, Michigan Department of Environmental Quality.
- *Status of the Clinton River Area of Concern*. Mark Richardson, Chair, Public Advisory Council and Assistant Prosecutor, Macomb County Prosecutor's Office; and Jessica Pitelka Opfer, Executive Director, Clinton River Watershed Council.
- *Detroit River -- U.S. side*. Jeannine Ansley, Chair, Remedial Action Team Steering Committee.
- *Detroit River -- Canadian side.* Douglas Haffner, University of Windsor and member, Detroit River Canadian Clean Up Committee.

The WQB also had the opportunity to engage in informal and candid discussions.

2.4.2 Findings of the Great Lakes Water Quality Board

The WQB presented the following findings and advice to the IJC on May 8, 2003.

The key points emerging from the consultation were the following.

Common issues among the Rouge River, Clinton River, and the U.S. portion of the Detroit River Areas of Concern are combined sewer overflows, storm water runoff, contaminated sediment, and habitat loss. Other issues include illicit connections and septic system failures. The WQB is impressed by the commitment of the local citizenry for the restoration of all three Areas of Concern, including education and outreach to secure public involvement, support, and stewardship. However, the Remedial Action Plans are at dramatically different points in their work:

- The Rouge River Remedial Action Plan is well organized and, thus far, funded for planning. More than $920 million (USD) has been spent, but an additional $700 million is needed for infrastructure improvements to comply with permit requirements and corrective action agreements.
- After a two-year hiatus, the Clinton River Remedial Action Plan is now part way through the planning process. The Remedial Action Plan does not at present provide specifics or priorities in regard to major problems and their resolution. Funds are required to support the planning process.
- The U.S. portion of the Detroit River Remedial Action Plan appears to be at the initial stages of the planning process. Funds are required to support planning.
- The Canadian portion of the Detroit River Remedial Action Plan has implemented a number of remedial measures.

The driving factors for all three U.S. Areas of Concern is achievement of compliance with federal and state regulatory requirements. Although restoration of beneficial uses, as called for in the Agreement, are considered, this does not appear to be a driving force for the Remedial Action Plans.

A key requirement for the Rouge River, Clinton River, and the U.S. portion of the Detroit River Remedial Action Plans is funding, as appropriate, to plan and implement remedial actions, but forthcoming state budget cuts will further impact local governments' ability to do so. The monies are required to meet regulatory requirements; the Rouge River Remedial Action Plan has considered but has not costed out the additional funds required to restore beneficial uses.

Another key need for the three Remedial Action Plans is more active engagement and direction by the federal and state governments. No single entity oversees each Remedial Action Plan, which raises questions of responsibility and accountability for ensuring that necessary remedial actions are accomplished. The absence of active engagement by the state of Michigan with the Rouge River and Detroit River Remedial Action Plans was particularly noted, but this may have reflected the state's view that Remedial Action Plans are a federal responsibility.

Michigan has participated with the Clinton River Remedial Action Plan, but a number of different people have held the liaison position over the past few years, and the current representative is assisting with multiple Remedial Action Plans throughout the state. The U.S. Environmental Protection Agency has recently assigned a liaison with the Clinton River Remedial Action Plan.

Local groups are well suited to undertake ground up planning, but the state of Michigan and the U.S. federal government must actively engage in order to:

- ensure properly formulated and focused plans that meet not only local goals but also state and federal regulatory requirements and Agreement goals;
- facilitate coordination and cooperation among the multiplicity of communities and local agencies that comprise each Area of Concern; and
- ensure ownership and accountability for both Remedial Action Plan development and, more importantly, implementation of remedial measures.

No single entity oversees each Remedial Action Plan, which raises questions of responsibility and accountability for ensuring that necessary remedial actions are accomplished.

The need for more active engagement by the federal, state, and provincial governments may also apply to other Areas of Concern. This may be a topic for consideration by the IJC's Annex 2 Task Force.

Another issue that applies across the basin is information and knowledge management and corporate memory. Remedial Action Plan personnel at the local, state / provincial, and federal levels are not necessarily aware of scientific and technical information that may be relevant to define or understand problems or to implement solutions. This is particularly true when knowledgeable people leave and new people arrive. As a result, a considerable amount of time is spent on learning curves and re-discovering what

others already know. Suitable mechanisms are required to ensure that all who are involved with Remedial Action Plans have ready access to relevant information, knowledge, and experience of others.

The WQB recognizes that information and knowledge management and corporate memory is a major challenge, but one that requires direction at the federal level. The WQB acknowledges that a number of mechanisms are being used to manage and transfer information and knowledge, for example, binational workshops that focus on a particular beneficial use impairment, the WQB's various guidance reports such as for the assessment and remediation of contaminated sediment, and the Remedial Action Plan workshops held in conjunction with the IJC's biennial meetings. Other opportunities may be worth consideration, for example, an easily updatable loose-leaf handbook or orientation package that provides what one needs to know, or the DREAMS (Data Retrieval, Exchange, Archiving and Management System) program developed for the Detroit River, or a web-based communication network along the lines of that in place for the botulism issue.

Another suggestion to facilitate information sharing, planning, and implementation of remedial actions is to adopt a "corridor approach" that links the St. Clair River, Clinton River, Detroit River, Rouge River, and River Raisin Areas of Concern with the Lake Erie Lakewide Management Plan.

The WQB believes that information and knowledge management is a suitable topic for consideration by the IJC's Annex 2 Task Force.

2.4.3 Advice and Recommendations of the Great Lakes Water Quality Board

The WQB concludes that engagement, direction and funding by the federal and state governments are required to promote further progress to restore and protect the Rouge, Clinton, and Detroit rivers.

The WQB recommends the following to the International Joint Commission:

- **Recommend that the state of Michigan and the U.S. federal government more actively engage in the RAP process by providing strong and visible direction and core funding to support the Rouge River, Clinton River, and the U.S. portion of the Detroit River RAPs in the planning and implementation of remedial programs.**

At a minimum, the governments should provide funds to support planning, monitoring, remediation projects, and public participation through local communities. In addition, the federal, state, and provincial governments are in a position to provide technical expertise such as assistance to implement policy guidance. For example, they can provide advice on the utility of such initiatives as the TMDL (total maximum daily load) and non-point source control programs as tools to support Remedial Action Plan goals. The federal, state and provincial governments are also well positioned to undertake the evaluation of specific structural installations -- such as combined sewer overflow controls -- and non-structural measures, to determine long-term performance and whether specific options are appropriate and cost-effective to protect and improve water quality in a particular Area of Concern.

> The WQB notes that the four-agency agreement for the Detroit / St. Clair / St. Marys rivers may be a suitable mechanism to facilitate coordination within and among the Areas of Concern and with the Lake Erie Lakewide Management Plan. The four-agency agreement may also be a mechanism for sharing a wide range of relevant information.

The WQB concludes that engagement by federal, state and provincial governments, as well as knowledge and information management and transfer, are important throughout the basin.

2.4

The WQB recommends the following to the IJC:

- **Advise the governments on the importance of engagement by the federal, state and provincial governments for all Areas of Concern in the Great Lakes basin.**

- **Direct the Annex 2 Task Force to explore and advise on options and alternatives for knowledge and information management and transfer.**

The WQB notes that the four-agency agreement for the Detroit / St. Clair / St. Marys rivers may be a suitable mechanism to facilitate coordination within and among the Areas of Concern and with the Lake Erie Lakewide Management Plan. The four-agency agreement may also be a mechanism for sharing a wide range of relevant information.

The WQB notes that Remedial Action Plan planning and programs for the Detroit River are conducted independently on the two sides of the river. Although there are advantages to a binational approach, the WQB has no comment at this time.

2.5 GREAT LAKES SCIENCE ADVISORY BOARD ANNEX 2 ACTIVITIES

2.5.1 Annex 2 Task Force

During 2002, the IJC established a task force to provide expert advice on matters pertaining to Annex 2: Remedial Action Plans and Lakewide Management Plans. The task force comprises a lead IJC commissioner from each country, up to three Great Lakes Water Quality Board members, two Great Lakes Science Advisory Board members, a member from the Council of Great Lakes Research Managers, the director of the IJC's Great Lakes Regional Office, and a provision for additional individuals to be added as deemed necessary by the lead commissioners.

SAB members on the task force have gained insight on the Parties effort to clarify their interpretation of the *Great Lakes Water Quality Agreement* with respect to Lakewide Management Plans and the adequacy of information sharing and data dissemination efforts. The Parties have examined Lakewide Management Plan development and reporting and bilaterally determined to alter the reporting arrangements that are detailed in Annex 2 of the Agreement. However, it remains unclear to what extent the public was consulted prior to the modification of reporting and no formal arrangement has been devised to provide for IJC review and comment of the updated-style Lakewide Management Plan documents now being produced.

Valuable data and information, particularly in regard to the sources and loadings of critical pollutants, have been developed through Lakewide Management Plan activities. In particular, data that are currently available through the Lake Michigan Mass Balance Project are useful in targeting specific sources of critical pollutants so that appropriate measures can be directed to reducing existing loads. However, at least in the United States, funding for Annex 2 activities has been greatly reduced from its 1992 level. With the present level of funding, it appears that information sharing activities as well as surveillance and monitoring programs may experience considerable competition for available funds.

In its chapter of the 1997-99 Priorities Report, the SAB assessed scientific issues related to Lakewide Management Plans and noted that the development and implementation of a Lakewide Management Plan is a difficult task, particularly as it relates to defining the threat to human health from critical pollutants. While there have been modifications to the Parties' Lakewide Management Plan process, the recommendation suggesting that the Parties demonstrate that the Lakewide Management Plan process represents a best management effort in terms of information sharing and dissemination and adequacy of current surveillance and monitoring programs remains viable. In addition, the SAB recommended that the Parties clarify their interpretation of the *Great Lakes Water Quality Agreement* with respect to the development of Lakewide Management Plans -- this also remains salient today.

During 2002, the IJC established a task force to provide expert advice on matters pertaining to Annex 2: Remedial Action Plans and Lakewide Management Plans. The task force comprises a lead IJC commissioner from each country, up to three Great Lakes Water Quality Board members, two Great Lakes Science Advisory Board members, a member from the Council of Great Lakes Research Managers, the director of the IJC's Great Lakes Regional Office, and a provision for additional individuals to be added as deemed necessary by the lead commissioners.

2.5.2 Site Visit and Public Meeting in the Maumee River Area of Concern

In keeping with the practice of the SAB to hold an annual public meeting, its 125th meeting was held in Toledo, Ohio, on May 1-2, 2002. The meeting provided several opportunities for site visits related to planning initiatives in the Maumee watershed, to review progress in the implementation of the Maumee Remedial Action Plan, and to receive public input on scientific issues in the Area of Concern. In order to accomplish this ambitious agenda, excellent assistance and cooperation was provided locally from Ohio EPA and the Toledo Metropolitan Area Council of Governments. Through their auspices, a public meeting was held on the evening of May 1 and was well attended by stakeholders and Remedial Action Plan planners.

Observations and comments from the site visits and public meeting were then developed by the SAB and forwarded to the IJC under separate cover, based on the meeting summary, the SAB noted that community support and interest in the Maumee Area of Concern are outstanding, reflecting long established commitment, effective local leadership and the efforts of a locally based Remedial Action Plan coordinator who has greatly facilitated and assisted the planning process. The planned termination of this position could significantly affect the ability of the community to sustain the momentum and local volunteerism to achieve future progress.

While some research support from local universities is evident, an opportunity exists for greater research involvement with the community if a formal research plan and strategy were developed to facilitate scientific partnerships, collaboration and cooperation that would serve to identify and address Remedial Action Plan research needs. A Maumee Remedial Action Plan Science Advisory Board could fulfill an important advisory role to the local planning process. Access to major grants is often based on public/private partnerships that address long-term issues related to real community needs. The result would be a strengthened linkage of science and policy in support of restoration.

Overall progress based on voluntary actions, limited resources and extensive local support from Ohio EPA and U.S. EPA has been significant. For final delisting to occur however, there are large-scale, long-term challenges, such as final clean up on the Ottawa River to protect human, wildlife and fish health, which will require increased resources and significant support from senior levels of government to achieve restoration. The impact of the Ottawa and Maumee rivers on Maumee Bay (Lake Erie) sediment loads needs to be addressed as part of the Remedial Action Plan.

A role for the IJC was identified to assist Area of Concern coordinators with information sharing, and better reporting of Remedial Action Plan successes, in order to promote Remedial Action Plan implementation and restoration efforts more effectively throughout the basin.

2001-2003
Priorities Report
Chapter 3

URBANIZATION: THE LAND USE - WATER QUALITY LINKAGE

CHAPTER THREE Urbanization: The Land Use - Water Quality Linkage

Contents

Report of the Great Lakes Science Advisory Board

Note: All references in this chapter are found in Section 7.9

3.1 INTRODUCTION

The impact of urban and urbanizing development on Great Lakes water quality has been an issue of growing concern to the Great Lakes Science Advisory Board (SAB) since 1997. The International Joint Commission's (IJC) interest in the issue dates back to the seminal 1978 study of its Pollution from Land Use Activities Reference Group or PLUARG. That study, which definitively linked urbanization and associated improper land-use practices to water quality degradation, has been followed by a substantial amount of work to document the environmental threats of such activity and develop best management practices to minimize or eliminate impacts.

Despite the increased focus, however, the SAB notes that the trend toward urbanization is accelerating and adverse impacts on the Great Lakes basin ecosystem are increasingly apparent. The SAB's Work Group on Parties Implementation examined the land-use/water quality linkage in detail through policy research, literature review, case study analyses, a workshop, and expert consultation. Among other questions, the work group documented the relevance of land use to multiple articles and annexes of the *Great Lakes Water Quality Agreement*; explored options for the prevention and management of urban water quality impacts; and examined the challenges associated with an issue that has historically been under the jurisdiction of local governments.

Significant additional work needs to be accomplished in the basin and, toward that end, the SAB recommends that Canada and the U.S., the parties to the *Great Lakes Water Quality Agreement*, undertake a major binational, investigation and research effort related to the land-use/water quality linkage to include a binational inventory and assessment of innovative policies and programs to protect urban and urbanizing watersheds; and a binational study of sewage treatment infrastructure and practices in the basin. The intent is to encourage the IJC, the Parties, institutions and other levels of government with a role and responsibility in Great Lakes management and protection to enhance their focus on land-use practices as determinants of Great Lakes water quality.

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3.2 EXPERT CONSULTATION ON THE IMPACT OF URBAN AND URBANIZING DEVELOPMENT ON GREAT LAKES WATER QUALITY

3.2.1 Introduction

Governments and organizations have been studying the impacts of urbanization on the natural environ ment, and the Great Lakes specifically, since the 1970s (Waller 1981; Marsalek 1991; U.S. EPA 1983). The IJC first looked at urbanization and its impact on the Great Lakes through the Pollution from Land-Use Activities Reference Group (PLUARG) process. The PLUARG final report, released in 1978, was definitive in its finding that urbanization is a significant contributor to the water quality problems of the basin (IJC 1978). Since PLUARG, recent studies have continued to identify urban land-use development as a major source of stress to the Great Lakes ecosystem. In 1996, the State of the Lakes Ecosystem Conference (SOLEC) highlighted this issue in the context of its theme, The Year of the Nearshore, and documented extensive threats from nonpoint source pollution affecting lakes Michigan, Erie and Ontario. SOLEC concluded that growth and development, notably urban sprawl, were seriously impacting the region through land-use changes in the Great Lakes basin.

Much has been done in response to the environmental problems associated with urbanization in the Great Lakes basin and beyond. Many local, regional and state/provincial governments have embraced tools such as watershed planning, urban growth boundaries and conservation design within Areas of Concern and elsewhere. "Smart Growth" initiatives, sponsored by a number of U.S. states and Canadian provinces, have accomplished a great deal with respect to educating decision-makers and the general public about urban growth and its impacts on environmental features such as the Great Lakes.

As more is being done and more is known about the impacts of urbanization on water quality (Novotny 1992; Ellis 1996; Hermann 1997; Pandit 1997), the trend over the past 20 to 30 years has been toward even greater urbanization. This trend is accelerating and is producing profound negative effects on local aquatic ecosystems throughout North America (U.S. EPA 2000). In the Great Lakes, urban areas of the basin continue to grow and the impact on Great Lakes water quality continues to be an important issue for the region (Pijanowski *et al*. 2002). Put simply, the IJC needs to continue to be active on the urbanization issue, adding to the work that is being done by others (e.g. Smart Growth initiatives) and addressing the specific issues in relation to the *Great Lakes Water Quality Agreement.*

Review of SOLEC Indicators of Land Use

In this cycle, the Work Group on Parties Implementation commissioned a report by senior undergraduate environmental science students at the University of Guelph, Ontario, which assessed the current list of SOLEC land-use indicators to determine their simplicity, scope, sensitivity, potential for quantification, and availability of specific numerical targets. The following eight indicators were the focus of this evaluation:

1) Extent of Hardened Shoreline (ID#8131)
2) Area, Quality and Protection of Great Lakes Islands (ID#8129)
3) Agriculture (ID#7028)
4) Citizen/Community Place-Based Stewardship Activities (ID#3513)
5) Green Planning Process (ID#7053)
6) Brownfield Redevelopment (ID#7006)
7) Urban Density (ID#7000)
8) Mass Transportation (ID#7012)

Although SOLEC proposes to use these indicators to assess a broad range of potential environmental impacts, the evaluation examined in particular the utility of the indicators for reporting progress under the Great Lakes Water Quality Agreement. The conclusions of this review showed that all of the proposed SOLEC indicators will require refinement before they can be applied in Great Lakes reporting. In no case was a clear relationship established between the indicator and any particular environmental outcome. No indicator had proposed targets established, and in most cases even the definitions of desired outcomes or activities were unclear (e.g. "sustainable agriculture"; "stewardship activity"). In some cases, it was not clear that any relationship between the indicator and any environmental outcome even exists. Several proposed indicators imply that the existence of a particular institutional arrangement, such as a management plan, will ensure a beneficial environmental outcome. In fact, such plans may vary widely in nature, extent, and environmental impact, so the simple existence of a plan is not an effective predictor of water quality, habitat alteration, or any other environmental condition. The review also suggested that the site-specific nature of many management practices would make it difficult to develop the kind of broadly- applicable relationships that would be necessary to implement these indicators.

3.2.2 SOLEC Indicators

Since the 1996 State of the Lakes Ecosystem Conference, SOLEC organizers and participants have attempted to develop and refine a suite of ecological and socio-economic indicators for the Great Lakes basin ecosystem. SOLEC indicators provide a method for measuring progress toward meeting the terms of the *Great Lakes Water Quality Agreement*. SOLEC indicators are selected based on three general criteria: necessity, sufficiency and feasibility. The 1996 SOLEC paper, *Impacts of Changing Land Use*, included an initial list of 36 Great Lakes land-use indicators. That list has been revised during subsequent SOLEC events. There are presently 12 SOLEC indicators under the category of "land and land-use" among a broader suite of 118 ecosystem indicators, many of which are also related to land use. See the inset for details of a review some of the land and land-use indicators.

3.2.3 Consultant Background Work

To examine and build on the scientific understanding of linkages between urbanization and water quality, the SAB's Parties Implementation Work Group contracted with GHK International Consulting (Toronto, Ontario), to examine urbanization trends in six Great Lakes city-regions: Chicago, Milwaukee, and Duluth in the United States; and Toronto, Windsor, and Collingwood in Canada. The selected focus areas were to provide samples of varying size and lake basin. For each city-region, the consultant was asked to forecast and map population growth and urban boundaries to 2031 and comment on water quality impacts, infrastructure demands, potential mitigation methods (e.g. best management practices, conservation design) and policy implications. The consultant was also asked to look specifically at five indicators related to water quality for each city-region: phosphorus, total suspended solids, copper, imperviousness and estradiol.

For three parameters, the consultant compared data from Canadian sewage treatment plants with storm-water runoff. *(Data from U.S. STPs was unavailable, in part due to security reasons.)* Based on analysis of the three Canadian city-regions on a per-capita basis, the findings for three of the parameters were:

- total suspended solids discharges were comparable or greater for sewage treatment plants than for storm water;
- phosphorus discharges were about 50 times greater from sewage treatment plants than from storm water; and
- copper discharges were between 2.5 to 20 times greater from sewage treatment plants than from storm water.

Large variations among sewage treatment plants for total suspended solids suggest the need for better data collection and improved methods of estimation for this parameter. For phosphorus and copper, the findings suggest that sewage treatment plant discharges are greater than storm water on a *per capita* basis. This finding reinforces the significance of improving and maintaining sewage treatment plants, which are associated with urbanized and urbanizing (e.g. urban and suburban) areas. In addition to overall amounts discharged, the way in which these compounds reach our water ways is also a consideration. Additional research could improve our understanding of the implications of different deliveries of contaminants on the physical (e.g. hydrologic) and chemical integrity of receiving waters.

At the same time, the consultant's findings suggest that *per capita* storm-water runoff decreases with increasing population density. This finding supports related research showing that increased impervious surface cover, associated with low-density development or sprawl, results in greater water quality degradation. However, the research did not examine effects of different urban forms, which would have required a separate study. This supports the need for further scientific inquiry comparing *per capita* discharge rates as a function of population density and urban form.

Increased vehicular use (vehicular distance traveled) associated with low density development and its contribution to contaminants in storm water and atmospheric deposition also was highlighted by the consultants. Due to time and resource constraints, the consultants were unable to specifically measure levels of impervious cover for the newly developing areas in the six city-regions studied. This would be an important area of continued inquiry. Findings regarding estradiol discharges were inconclusive due to considerable variability and uncertainty in the scientific literature and a lack available facility-specific data.

The 1996 SOLEC paper, *Impacts of Changing Land Use*, included an initial list of 36 Great Lakes land-use indicators. That list has been revised during subsequent SOLEC events. There are presently 12 SOLEC indicators under the category of "land and land-use" among a broader suite of 118 ecosystem indicators, many of which are also related to land use.

In summary, the consultant's work supported the concept that lower density development patterns result in increased *per capita* impervious surface, vehicular distance traveled, storm-water runoff and pollutant loadings and that additional research is needed to better understand the links between urbanization, urban form and water quality impacts. Studies that would build on the consultant's work include:

- a study of *per capita* discharges from different urban forms, such as dense urban areas, newly developing low-density areas at the urban fringe and new urbanist/ cluster development;
- a study of impacts from chronic (sewage treatment plants) versus sporadic (storm-water runoff) discharges into Great Lakes and tributaries; a study of wastewater treatment plant conditions, maintenance and improvement needs and costs based on population and urbanization projections; and
- examination and documentation of impervious surface coverage in the six city-regions and other urbanizing areas in the Great Lakes basin.

3.2.4 Workshop on the Impact of Urban and Urbanizing Development on Great Lakes Water Quality

On January 8, 2003, the Parties Implementation Work Group of the SAB held a workshop to discuss the impact of urban and urbanizing development on Great Lakes water quality. The workshop was intentionally small in scope and was limited to members of the work group, members of other IJC advisory boards (the Water Quality Board, the International Air Quality Advisory Board, and the Council of Great Lakes Research Managers), the work group's consultant, GHK International, and five invited keynote speakers. These speakers were:

- *John Sewell*, former Mayor of Toronto, Chair of the Commission on Planning and Development Reform in Ontario
- *Larry Bourne*, Professor and Director of the Centre for Urban and Community Studies, Department of Geography, University of Toronto
- *Tom Schueler*, Director, Center for Watershed Protection, Ellicott City, MD
- *Lawrence Libby*, C. William Swank Professor of Rural-Urban Policy, Ohio State University
- *G. William Page*, Professor, Department of Urban and Regional Planning, University of Buffalo, State University of New York

The workshop began with a summary of the consultants' background research, which focused on forecast and analysis of urban development six case city-regions in the Great Lakes basin and implications for water quality. This summary was followed by a short presentation by each invited speaker addressing three questions:

- What is the ideal urban form to minimize land-use impacts on water quality?
- How could it be attained?
- What are the policy implications?

A roundtable discussion focused on the development of policy recommendations for the IJC and the Parties. It was clear from these discussions that this issue has immediate relevance for many sections of the *Great Lakes Water Quality Agreement*, in particular:

Article VI– Pollution from Municipal Sources and Pollution from Industrial Sources
Annex 1 – Specific Objectives
Annex 2 – RAPs and LaMPs
Annex 3 – Control of Phosphorus
Annex 10 – Hazardous Polluting Substances
Annex 11 – Surveillance and Monitoring
Annex 12 – Persistent Toxic Substances
Annex 13 – Pollution from Nonpoint Sources
Annex 14 – Contaminated Sediments
Annex 15 – Airborne Toxic Substances
Annex 16 – Contaminated Groundwater

3.2.5 Workshop Participants' Deliberations and Policy Recommendations

Patterns of Population Growth and Urban Development in the Great Lakes Basin, 2002-2020

Evidence presented by the consultants and the invited speakers underscored the rapid urbanization now occurring in parts of the Great Lakes basin. In Chicago, for example, population growth approached 12 percent between 1990 and 2000, while in Toronto, between 1992-1997, the population grew 13.8 percent . Population in these major centres is expected to increase steadily over the next 20 years. In Chicago, that growth is estimated at 7 percent between 2000 and 2010, slowing to 4 percent between 2010 and 2020; in Toronto, population is expected to increase by 16 percent between 2000 and 2011, with a further 10 percent between 2011 and 2021. Overall, GHK estimates that a further 3.3 million people will be added to the six case study cities by 2020. The link to Great Lakes water quality from these population increases is related to the type of development that occurs to accommodate more people. If the development is of a traditional urban design (relatively dense, mixed use, grid street pattern) the water quality impacts will be primarily from increased demands on sewage treatment plants with concentrated water quality impacts in certain watershed locales such as urban centers. If development occurs in the low-density sprawling pattern that has been predominant since World War II, the impacts will be more due to increased runoff from increased impervious surfaces across the watershed, and deposition of air pollutants that come from increased vehicular traffic associated with this urban form. Because current development patterns are primarily sprawl, this population growth will likely be accompanied by substantial land conversion from rural uses, such as agriculture, to urban and suburban uses. Lower density development means that the rate of land conversion outpaces that of population increase. The rate of land conversion is expected to be greatest on the U.S. side of the basin and may be 50 percent or more in some metropolitan areas. With lower development density more roads and highways are necessary to connect the built environment, and more people are required to drive longer distances to get to and from home, jobs, shopping, etc. Accordingly, the projected population growth will include an increase in daily vehicle distance traveled, which in some parts of the basin is growing much faster than the rate of land conversion. For example, Chicago's population grew 9.6 percent between 1982 and 1997, its urbanized area grew by 25.5 percent and its vehicle distance traveled by 79 percent over the same period.

This development pattern is not, however, uniform across all Great Lakes city-regions. Speaker Larry Bourne noted that 85 percent of Ontario's population growth is occurring in the "Golden Horseshoe," the northwestern portion of Lake Ontario between Niagara and Port Hope. In many parts of the basin, there has been a migration from rural to urban or suburban lands; at the same time, many U.S. centres are experiencing migration from inner cities to suburban lands. In either case, the most pressing development challenge therefore occurs at the urban fringe. Patterns of urban development also vary from region to region. GHK's findings suggest that the Canadian city-regions studied (Toronto, Collingwood, and Windsor) have exhibited more compact development than their U.S. counterparts. For instance, while the Toronto area population grew 13.8 percent between 1992 and 1999, its urbanized land area grew by only 8 percent. By contrast, the Milwaukee area population grew 6.5 percent between 1982 and 1997, its urbanized land area grew by 24.9 percent over the same period. Several factors may account for this contrast: differences in the way that urbanized land is measured; differing land development (i.e. urban) forms in each city-region; the location and character of major industrial complexes and the transportation corridors serving them; and different laws and regulations regarding acceptable development patterns.

Various speakers commented on the dramatic reduction in household size (i.e. number of individuals in each household) over the past several decades. Like population density, household density also has decreased and is an indicator of demographic shifts, but has limited application as an indicator of urbanization, or overall development density. An effective measurement of urbanization should measure *the density of development*, including commercial, industrial, warehousing, transportation corridor as well as residential and other types of development.

The Water Quality Impacts of Urbanization

The consultants' findings support numerous other studies showing that urbanization changes surface water quality in fundamental ways. Three principal sources exist: treated effluents and bypass from wastewater (sewage) treatment plants; treated and untreated urban storm-water runoff ; and combined sewer overflows, carrying a mixture of untreated sanitary sewage and storm water. GHK's results confirm that sewage treatment plants can be important sources of suspended solids, phosphorus and nitrogen, metals, and a variety of chemicals used in pharmaceutical and cosmetic preparations. Storm water contributes suspended solids, phosphorus and nitrogen (primarily from animal excrement and lawn fertilizers), and metals, but in addition can be an important source of polynuclear aromatic hydrocarbons (PAHs) from vehicle exhaust and other atmospheric sources, as well as microorganisms from animal excrement. There is considerable variation in the degree to which these sources contribute to water quality impairments. Factors influencing this contribution include the level and type of treatment practices (i.e. storm-water management) applied to a given stream, and the relative contributions of industrial, commercial and residential wastewaters to each stream in a particular region.

Notwithstanding differences from city to city and from inner city to suburban regions, one fact was clear from these discussions: the population of the Great Lakes basin will continue to spread out faster than it increases over the next 20 years. This sprawling development trend will mean more sewage requiring treatment in urban and suburban areas, more paved and roofed surfaces over which precipitation will rapidly flow, and airborne pollutant loadings from increased vehicle distance traveled. Although it is unlikely that society can control the rate of growth, it can make choices about ***where*** urban development will occur, and ***how*** that development is configured. Those decisions will be taken under the current land-use planning and approval process in each jurisdiction.

Urban Impact on Water Quality

Tom Schueler presented persuasive evidence from the Center for Watershed Protection demonstrating that impervious cover is a much better measure of the impact of urbanization than is population density. He observed that two trends are evident in modern land-use planning. First, the scale of most buildings, from residential dwellings to churches and malls, is increasing -- everything is larger now than it was 50 or 100 years ago. And second, two-thirds of all impervious cover is now "car habitat": roads, parking lots, and driveways. It is this "car habitat" that should therefore be a principal focus of urban design. The Center for Watershed Protection has reviewed more than 225 research studies linking 26 urban stream indicators to impervious cover, and on the basis of these findings has developed a basic Impervious Cover Model. The Impervious Cover Model predicts that:

- watersheds with less than 10 percent impervious cover should have the potential for good water quality; where that good quality is not realized, the cause may be historic alteration rather than land-use. Ten percent impervious cover is typical of rural to suburban development with "estate" lots 0.5 to 1 hectare in size;
- watersheds with 10 to 25 percent impervious cover can experience moderate degradation, but that degradation can be mitigated by careful site design and storm-water treatment practices. Most suburban development is typically within this range of impervious cover; and
- watersheds with more than 25 percent impervious cover typically cannot support designated beneficial uses and exhibit degraded water quality. Active infill/redevelopment strategies will increase impervious cover in older urban watersheds, thus potentially avoiding the development of greenfields. The costs of such infill however average roughly 10 times those of storm-water treatment facilities constructed on a "greenfield" site.

Mr. Schueler emphasized the need for upland reclamation and reforestation as part of an integrated "smart watershed" strategy.

Several speakers noted that measures of vehicle distance traveled is very useful as a surrogate measure of vehicular emissions. Since increased road travel is a notable difference between traditional urban development and low-density sprawl development, vehicle distance traveled is a potentially important indicator for examining water quality impacts from different urban forms. It may also be the best available estimate of the distribution of jobs and the labour force.

The Ideal Urban Form

Although participants agreed that no particular urban form offered a "silver bullet" for the resolution of urban water quality impacts, there was considerable support for the notion that four elements of urban form can reduce the quantity and improve the quality of urban runoff. These elements are:

- compact development;
- mixed uses;
- short blocks; and
- respect for natural systems.

The first three of these were originally articulated by the distinguished urban planner Jane Jacobs; the last was proposed by John Sewell and endorsed by other participants. All are consistent with the principles of "new urbanism" now widely debated. Yet Larry Bourne argued that many new urbanism communities have accommodated these principles while failing to address issues of access to employment, and thus ignore traffic and related emissions.

The Center for Watershed Protection has developed a number of principles for the development of suburban and urban watersheds that incorporate these principles. (see Appendix I)

The Land Use Planning/Approval Process

The work group has long suspected that institutional arrangements are critical to managing the water quality impacts of urbanization, and indeed emphasized that point in the SAB's 1999-2001 Priorities Report, which stated:

This need for site-specific approaches may underlie much of the management challenge of NPS [nonpoint source] pollution. In particular, the current research suggests that control of NPS [nonpoint source] pollution has been hampered by:

- insufficient persuasive evidence of the effectiveness of best management practices;
- lack of performance standards;
- inadequate financial incentives for clean-up; and
- *inadequate institutional arrangements.*

Current research further underscores the importance of institutional arrangements. Several key points were made. John Sewell reminded participants that Ontario's current system of land-use planning and urban design is not based on the public good, but on what developers and investors can sell in the real estate market. Although planning documents, such as official plans, reflect the good intentions of the municipality, they are often too general and too flexible to be a useful regulatory tool. Too frequently, official plans are amended to accommodate the demands of a particular developer.

On the U.S. side, much of land-use planning decisions are not based on comprehensive land-use plans (the equivalent of the official plan) but on zoning regulations. Zoning regulations carry the force of law, land-use plans do not.

Some states require zoning to be consistent with a comprehensive plan, though most do not. Similarly, local governments have the authority to regulate land use, but it is not a requirement.

Several speakers suggested changing the "price structure" of planning decisions, rather than attempting to regulate every stage in the planning and approval process. This would entail economic (tax) incentives for preferred forms of development, and disincentives for those forms to be discouraged. For example, free parking at suburban malls (especially in comparison to high inner city parking rates) hides the true environmental costs of suburban development from shoppers. Imposing parking fees at such malls would be a simple means of creating public awareness of these costs. As another example, municipalities might require new developments build storm-water treatment facilities, if their estimated impervious cover exceeded target levels. Developments within impervious cover targets could have treatment requirements waived. Similarly, infrastructure funding grants can and should be tied to the existence of an approved water quality improvement plan, a capital improvements plan, as well as approved comprehensive land-use plans. Disincentives could include removal of U.S. tax deductions for mortgages and capital gains, and similar hidden subsidies for large-home, low-density developments. This could also include removal of incentives for low-density commercial and industrial development in greenfields such as public subsidy of road and infrastructure improvements necessary to support those developments. Average cost pricing for public services, regardless of proximity to existing urban areas, is another type of hidden subsidy. These initiatives are being tried in a few selected areas, however, broad implementation of these policies throughout entire jurisdictions would have prospects for noticeable impact on current development patterns.

John Sewell suggested that developers be allowed more freedom to build what they like, provided that key conditions are met. Sewell cited the example of Toronto's King/Spadina District where the city of Toronto has relaxed development control regulations except with respect to desired setback and height requirements. It is conceivable that this approach could be used to secure limits on allowable impervious cover or road configuration, in order to reduce the quantity and improve the quality of storm water.

Several speakers also noted that there are tensions between local and regional planning interests. For example, it may be desirable to have no more than 10 percent impervious cover in a planning region. However, a given local area may experience pressure to exceed this percentage because of light industrial development opportunities associated with proximity to rail or shipping facilities. Both the local and the regional goals have legitimacy, though they are in apparent conflict. There is therefore a need to enable and indeed facilitate a public debate between local and regional interests to ensure that all goals are understood and the conflicts resolved. At least 10 states have implemented Growth Management Acts, and although these vary somewhat in form and content, they include requirements such as:

- statewide land-use planning goals and state land-use plans such as for impervious cover;
- concurrency between infrastructure capacity and new development;
- consistency between local, regional and state plans and state-legislated goals and regulations; and
- compactness of new growth.

The consistency requirement gives both the land-use plans and their implementing regulations, such as zoning, the force of law. As such, it remedies a basic flaw in institutional arrangements that governed land-use decision making.

Larry Bourne made the point that current measures of sprawl focus on residential land-use, however, non-residential uses, such as commercial and industrial uses, go largely unrecognized. Yet, non-residential uses create the most significant ecological and socio-economic impacts. From an ecological standpoint, non-residential land uses consume disproportionately large quantities of land for buildings and transportation networks from natural areas. Most of this development results in impervious cover and generates disproportionate amounts of emissions from large vehicles and of storm-water runoff. From a socio-economic standpoint the dispersal of non-residential uses increases the geographic separation between workplaces and housing. Bourne argued that it is the commercial and industrial uses that generate most of the vehicular traffic and emissions and use the most land on the urban periphery. Municipalities are often reluctant to restrict these types

There is broad consensus that urban water quality impacts can be reduced with careful site planning to reduce impervious cover and increase water detention.

of development because they generate employment together with immediate and measurable tax revenues. In part, these pressures derive from the increasing globalization of industry and the move to "mega scale" development in many industrial sectors.

John Sewell argued that municipalities should be investigating what Jane Jacobs termed "import replacement" (Jacobs 1961). That is, municipalities should be exploring opportunities to locally produce the goods and services that are currently imported from external sources with associated road networks and vehicular emissions. Import replacement may be a means of creating a range of employment opportunities, with associated economic development, closer to home, and thus reducing both industrial/commercial and commuting traffic.

Several speakers noted that development codes may best be redesigned through consensus-based programs such as Maryland's "Builders for the Bay." Consensus-based planning has great value in building support among those most affected by development changes, especially builders and developers, and has added advantages in creating a mechanism for broader public education.

Options for the Prevention and Management of Urban Water Quality Impacts

Lawrence Libby and William Page reviewed a number of options to prevent and manage water quality impacts from urban and urbanizing areas, as follows.

- ***Managing the geographic extent and ecological footprint of urban growth***

Municipalities can set distinct boundaries on urban growth, essentially by drawing a line on a map within which urban development may occur, known as urban growth boundaries. Urban growth boundaries are usually reviewed and revised every 20 years or so. Their efficacy may depend on how, when, and by whom these boundaries are enforced. A related concept is Urban Service Boundaries, which limit where central water and sewer services are provided. When coupled with a planning requirement that all new development must be served by centralized services, Urban Service Boundaries can *de facto* limit the extent of growth. Urban development boundaries may benefit from regional planning oversight, such as the Portland (Oregon) Metro system or Ontario's upper-tier municipalities like Metro Toronto.

- ***Protecting farmland***

If there is a concern with the conversion of productive farmland to urban or suburban development, a variety of policies and tools can be helpful in protecting farmland. These include agricultural zoning regulations, tax incentives, right to farm legal protections and agricultural districting. Purchase of development rights, otherwise known as purchase of agricultural conservation easements, and transfer of development rights are gaining increased attention as they preserve private ownership, and provide permanent protections for rural and agricultural lands. Purchase of development rights allows development rights to be sold to an entity, such as a state or local government or land trust, which holds on to that right to keep the land from being developed (in the form of a conservation easement). The land is retained in private ownership and continues to be used as rural or farmland. A transfer of development rights allows landowdners to transfer the right to develop one parcel of land to another parcel of land. When the development rights are transferred, the parcel that "sent" the development rights becomes restricted with a permanent conservation easement, much like purchase of development rights, and the parcel that "received" the development rights is allowed to develop at a higher density than ordinarily permitted in that area. The transfer of development rights is more complex to establish and administer and therefore is not as widely practiced as the purchase of development rights, but is gaining interest due to its ability to promote trading of rights among private parties in the interest of growth management.

- ***Reducing impervious cover and increasing water detention***

There is broad consensus that urban water quality impacts can be reduced with careful site planning to reduce impervious cover and increase water detention. The development principles (see Appendix I) of the Center for Watershed Protection (2003) emphasize these outcomes. They include changing planning and construction standards to allow:

- narrower street widths and smaller parking areas;
- reduced side and front setback requirements for residential dwellings (i.e. build houses closer together and closer to the street);
- roof downspout disconnection, with redirection of rooftop drainage to lawns and gardens;
- use of porous surfaces such as walkways and parking lots;
- use of grassed swales and other natural systems rather than paved surfaces or culverts;

- use of buffer strips along watercourses; and
- incentives and flexibility in the form of density compensation, buffer averaging, property tax reduction, stormwater credits, and by-right open space development to promote conservation of stream buffers, forests, meadows and other areas of environmental value.

These principles speak to the need for closer links between the land-use planning and approval process, and the water resources (or watershed) planning process.

- ***Full-cost pricing for water and sewerage services***

The need for full-cost pricing for water and sewerage services, identified in the SAB's 1999-2001 Priorities Report, is increasingly urgent. Without full-cost pricing, municipalities lack the necessary revenue stream for adequate system maintenance and replacement, but more importantly shield consumers from the true costs of using and often wasting water. Full-cost pricing would encourage more compact development with shorter sewer runs and a more concentrated, more effective treated municipal sewage stream.

The Need for Improved Research, Monitoring and Data Availability

Throughout these discussions, it became apparent that a lack of adequate monitoring data hampers the development of effective policy and the enforcement of existing rules. Particular gaps included:

- the lack of a systematic and integrated remote sensing system, which could be used to develop estimates of existing impervious cover and land use and to track changes over time;
- the lack of adequate data on vehicular emissions of air pollutants, which in turn may become important sources of pollution to watercourses. There is a need for targeted studies to evaluate the relative contributions of different vehicle types, such as passenger cars, SUVs, and small and heavy trucks;
- the lack of adequate data, and in some cases adequate detection methods, for "new" contaminants resulting from personal care, prescription drugs and other products for which there is preliminary evidence of important consequences;
- the lack of data on the relationship between water quality and different urban forms over watershed areas.

While the workgroup effort was able to better understand water quality impacts from different water treatment systems associated with urbanization, there was inadequate data and resources to examine how different urban development forms impact water quality. Given current demographic trends, it is critical to understand how we can accommodate population growth in a way that can minimize water quality and other environmental impacts while offering a high quality of life.

Sending a Message on Urban Land Use

Urban and urbanizing development is having a significant effect on Great Lakes water quality. The trend is toward an increasing effect. Through technology and policy changes – that affect how cities are designed and new growth is accommodated – these effects can be mitigated, but only if the necessary information is made available and if there is the public understanding of the issues to inform wise political decisions.

> The International Joint Commission's influence on Great Lakes water management has been particularly seminal and dramatic at three points in its long history. In 1912, the Parties asked the newly-formed IJC to examine and report on Great Lakes pollution. The IJC reported that pollution in the basin was "everywhere chaotic," prompting the Parties to begin discussions on binational pollution abatement measures. In 1946, again at the request of the Parties, the IJC considered the problem of pollution in the connecting channels. Noting that sewage treatment had not kept pace with population growth in the basin, the 1950 report on this reference points to injury to human health and property, indeed "major concern," with respect to pollution with bacteria, phenols, oil, iron, phosphorus, chloride, and other problems. The IJC's influence in this situation was one of the driving forces leading to the establishment of standards of practice for sewage treatment in the basin. Finally, in 1972, shortly after the signing of the first *Great Lakes Water Quality Agreement*, the Parties asked the IJC to investigate pollution from land-use activities. Six years and hundreds of research reports later, the Pollution from Land Use Activities Reference Group (PLUARG) produced a body of work that continues to influence the management of diffuse pollution sources today. As with so many of the IJC's activities, the importance of PLUARG lay not only with its technical contribution, but also in its demonstration of how governments and other organizations could work together to improve environmental conditions in the basin. In each of these cases, the IJC has been uniquely positioned to provide both a binational perspective on complex pollution problems, and a binational forum for the development of practical solutions. Its influence is apparent throughout the basin today, in municipal sewage treatment standards, agricultural practice and binational cooperation on every aspect of Great Lakes management.

As in all land-use activities, the decisions that most influence urban land use are made locally by municipal councils, zoning commissions and local permitting agencies. At the senior levels of government, the influence on local urban land-use decisions diminishes. State, provincial, and especially federal governments only have indirect authorities, such as general regulations and funding mechanisms, to influence land-use decisions. Nevertheless, local efforts to manage urban growth do require support, assistance and leadership from senior levels of government, for example, in the area of transportation policy.

How then, can the IJC best advise the Parties to send a message of support and leadership to lower levels of government in adopting urban land-use policies that will help protect the Great Lakes? This question faced the IJC and the Parties in the early 1970s when it was becoming clear that agricultural land use was affecting Great Lakes water quality. The answer then was a reference from the Parties to the IJC on pollution from land-use activities. The multi-year study that resulted, commonly called PLUARG, was the first comprehensive examination of land use in the Great Lakes basin.

While the reference included all kinds of land use, the study that resulted from it provided information and recommendations that had the most influence on agricultural land use. Farmers throughout the basin learned from this work. They heard the message and modified the way in which they used the land. Today, a large percentage of farm land is managed in ways that reduce or prevent soil loss (and the associated pollutants) and the resulting sedimentation of rivers and bays.

There is again a need to send a message and transmit the information needed to address the growing threat to Great Lakes water quality posed by urban and urbanizing development. Much of the information needed to address this threat already exists, as discussed above. It may well be that another PLUARG-style study will be needed to help ensure that the information is heard and understood by those involved in urban land use in all jurisdictions throughout the Great Lakes basin.

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It is suggested that it may be time for another International Field Year of the Great Lakes. The last International Field Year of the Great Lakes happened in 1972. The “Reference to the International Joint Commission to Study Pollution in the Great Lakes System from Agriculture, Forestry and other Land Use Activities” was dated that same year. Both activities were very positive for the Great Lakes. Thirty-one years later, it is time to reassess how far we have come in addressing past issues and to identify measures that protect the Great Lakes from the effects of increasing urbanization.

Recommendation

The SAB recommends the following to the IJC.

- **Recommend that the Parties undertake a major binational investigation and research effort on the effects of urban and urbanizing development on Great Lakes water quality and develop a comprehensive response to these effects.**

This work should be large-scale and comprehensive like the PLUARG study done in the 1970s but with an exclusive focus on urban and urbanizing development in the Great Lakes basin. It should characterize the scope of the problem, bring together information useful in addressing the problem, and produce recommendations to be implemented at all levels of government. The effort should be open to all interested stakeholders and every effort should be made to make the results widely available and understood. The study should be built on urban growth management work being implemented at the provincial/state and municipal levels. The study could be part of any International Field Year of the Great Lakes program that might be undertaken. Some key aspects of the problem that should be addressed in the investigation are:

- a projection of expected urban growth in the next 50 years throughout the Great Lakes basin;
- the relationship between the quantity of impervious cover in different urban forms and effects on water quality;
- the relationship between vehicular emissions generated in different urban forms and effects on water and air quality;
- an inventory and assessment of innovative programs and policies, such as full cost pricing, taxes, transportation programs, infrastructure upgrades, and tradeable permits, for the protection of water quality from the impacts of urban and urbanizing areas; and
- an examination of sewage treatment infrastructure and practices in the Great Lakes basin to assess their adequacy to serve future urban population and to treat waste stream contaminants not anticipated when most such systems were designed such as personal care and pharmaceutical products.

APPENDIX 1: MODEL LAND DEVELOPMENT PRINCIPLES DEVELOPED BY THE CENTER FOR WATERSHED PROTECTION
(Center for Watershed Protection/http://www.cwp.org)

Strategies for Rural Watersheds (0 to 10 percent Impervious Cover)

One of the major implications of the impervious cover model is that it predicts negative stream impacts at an extremely low intensity of watershed development, in the absence of watershed treatment. To put this in perspective, consider that a watershed zoned for two-acre lot residential development will generally exceed ten percent impervious cover, and, therefore shift from a sensitive to an impacted classification. Thus, if a community wishes to protect an important water resource or a highly regarded species, such as trout, salmon or an endangered freshwater mussel, the impervious cover model suggests that there is a maximum limit to growth, which is not only quite low, but is usually well below the current zoning for many suburban or even rural watersheds.

It is not surprising, then, that debate has quickly shifted to the issue of whether watershed treatment practices can provide adequate mitigation for impervious cover model. (For example, can stream buffers, storm water treatment practices, better site design and other forms of watershed treatment allow greater development density within a given watershed?) Only a limited amount of research has addressed this question, and the early results are not reassuring. At this early stage, researchers are still having trouble detecting the impact of watershed treatment, much less defining it. Both our watershed research techniques and ability to implement watershed treatment need to greatly improve before we can expect a scientifically defensible answer to this crucial question. Until then, managers should be extremely cautious in setting high expectations for how much watershed treatment can mitigate impervious cover.

As a consequence, land-use plans for rural watersheds should limit impervious cover to less than 10 percent, particularly if monitoring confirms that the streams are of excellent quality. Other key strategies include agricultural zoning, aggressive land conservation, wide stream buffers, and prohibition of sewers. Any development that does occur should be clustered in village centers, rather than distributed in large lots across the landscape.

Strategies for Suburban Watersheds (10 to 25 percent Impervious Cover)

Principle 1

Design residential streets for the minimum required pavement width needed to support travel lanes; on-street parking; and emergency, maintenance, and service vehicle access. These widths should be based on traffic volume.

Principle 2

Reduce the total length of residential streets by examining alternative street layouts to determine the best option for increasing the number of homes per unit length.

Principle 3

Wherever possible, residential street right-of-way widths should reflect the minimum required to accommodate the travel-way, the sidewalk, and vegetated open channels. Utilities and storm drains should be located within the pavement section of the right-of-way wherever feasible.

Principle 4

Minimize the number of residential street cul-de-sacs and incorporate landscaped areas to reduce their impervious cover. The radius of cul-de-sacs should be the minimum required to accommodate emergency and maintenance vehicles. Alternative turnarounds should be considered.

Principle 5

Where density, topography, soils, and slope permit, vegetated open channels should be used in the street right-of-way to convey and treat storm-water runoff.

Principle 6

The required parking ratio governing a particular land-use or activity should be enforced as both a maximum and a minimum in order to curb excess parking space construction. Existing parking ratios should be reviewed for conformance taking into account local and national experience to see if lower ratios are warranted and feasible.

Principle 7

Parking codes should be revised to lower parking requirements where mass transit is available or enforceable shared parking arrangements are made.

Principle 8

Reduce the overall imperviousness associated with parking lots by providing compact car spaces, minimizing stall dimensions, incorporating efficient parking lanes, and using pervious materials in the spillover parking areas where possible.

Principle 9

Provide meaningful incentives to encourage structured and shared parking to make it more economically viable.

Principle 10

Wherever possible, provide storm-water treatment for parking lot runoff using bioretention areas, filter strips, and/or other practices that can be integrated into required landscaping areas and traffic islands.

Principle 11

Advocate open space design development incorporates smaller lot sizes to minimize total impervious area, reduce total construction costs, conserve natural areas, provide community recreational space, and promote watershed protection.

Principle 12

Relax side yard setbacks and allow narrower frontages to reduce total road length in the community and overall site imperviousness. Relax front setback requirements to minimize driveway lengths and reduce overall lot imperviousness.

Principle 13

Promote more flexible design standards for residential subdivision sidewalks. Where practical, consider locating sidewalks on only one side of the street and provide common walkways linking pedestrian areas.

Principle 14

Reduce overall lot imperviousness by promoting alternative driveway surfaces and shared driveways that connect two or more homes together.

Principle 15

Clearly specify how community open space will be managed and designate a sustainable legal entity responsible for managing both natural and recreational open space.

Principle 16

Direct rooftop runoff to pervious areas such as yards, open channels, or vegetated areas and avoid routing rooftop runoff to the roadway and the storm-water conveyance system.

Principle 17

Create a variable width, naturally vegetated buffer system along all perennial streams that also encompasses critical environmental features such as the 100-year floodplain, steep slopes and freshwater wetlands.

Principle 18

The riparian stream buffer should be preserved or restored with native vegetation. The buffer system should be maintained through the plan review delineation, construction, and post-development stages of development.

Principle 19

Clearing and grading of forests and native vegetation at a site should be limited to the minimum amount needed to build lots, allow access, and provide fire protection. A fixed portion of any community open space should be managed as protected green space in a consolidated manner.

Principle 20

Conserve trees and other vegetation at each site by planting additional vegetation, clustering tree areas, and promoting the use of native plants. Wherever practical, manage community open space, street rights-of-way, parking lot islands, and other landscaped areas to promote natural vegetation.

Principle 21

Incentives and flexibility in the form of density compensation, buffer averaging, property tax reduction, storm-water credits, and by-right open space development should be encouraged to promote conservation of stream buffers, forests, meadows, and other areas of environmental value. In addition, off-site mitigation consistent with locally adopted watershed plans should be encouraged.

Principle 22

New storm-water outfalls should not discharge unmanaged storm water into jurisdictional wetlands, sole-source aquifers, or sensitive areas.

Strategies for Urban Watersheds (>25 percent Impervious Cover)

Principle 1

Conduct Environmental Assessments. Redevelopment and infill planning should include environmental site assessments that protect existing natural resources and identify opportunities for restoration, where feasible

Principle 2

Protect and Restore Natural Areas. Plan and design naturally vegetated areas and to encourage re-vegetation, soil restoration and the utilization of native and non-invasive plants where feasible.

Principle 3

Maintain Natural Areas in the Long-term. Establish mechanisms to guarantee long-term management and maintenance of all vegetated areas.

Principle 4

Make efficient use of Impervious Cover. Sites should be designed to utilize impervious cover efficiently and to minimize storm-water runoff. Where possible, the amount of impervious cover should be reduced or kept the same. In situations where impervious cover does increase, sites should be designed to improve the quality of storm-water runoff at the site or in the local watershed.

Principle 5

Employ Better Site Design on infill projects to maximize storm-water runoff and maximize vegetated areas

Principle 6

Maximize Transportation Choices. Design sites to maximize transportation choices in order to reduce vehicle miles travelled and improve air and water quality.

Principle 7

Manage Rooftop Runoff. Manage rooftop runoff through storage, re-use, and/or redirection to pervious surfaces for storm-water management and other environmental benefits

Principle 8

Design Courtyards/Plazas for Storm-water Treatment. Design courtyards, plazas and amenity open space to store, filter or treat rainfall. Examples include alternative pavers, bioretention and storm-water planters.

Principle 9

Minimize Parking and Treat Storm-water Parking lots, especially surface lots, should be minimized and designed to reduce, store and treat storm-water runoff. Where site limitations or other considerations prevents full parking lot runoff management, designs should target high use areas first.

Principle 10

Design Streetscapes to Treat Storm-water Design the streetscape to minimize, capture and reuse storm-water runoff. Where possible, provide planting spaces which promote the growth of healthy streets trees so that they can capture and treat storm-water runoff. In arid climates, xeriscapes should be used to achieve similar benefits.

Principle 11

Practice Pollution Prevention. Utilize proper storage, handling and site design techniques to avoid the contact of pollutants with storm-water runoff.

Proposed "Smart Watersheds" Programs for Municipalities

To ensure that any localized degradation caused by redevelopment and infill within urban watershed are more than compensated by stream quality improvements achieved by municipal restoration efforts, the Center for Watershed Protection has proposed a minimum level of municipal effort known as *smart watersheds*. Specifically, smart watersheds refers to 17 public sector programs that treat storm water runoff, restore urban stream corridors and reduce pollution discharges from highly urban watersheds (CWP 2003). The major elements of a smart watershed program are profiled below.

Program 1

Active Small Watershed Restoration Planning and Implementation. A smart watershed program engages in small watershed restoration efforts to ensure that any localized degradation caused by individual redevelopment and infill projects are more than compensated by improvements in overall watershed health. Specifically, a smart watershed program seeks to implement restoration projects over a watershed area that exceeds the total watershed area affected by infill and redevelopment projects.

Program 2

Subwatershed Mapping and Analysis. A smart watershed program will delineate and map all subwatersheds within the municipality on a GIS system. The GIS system will include accurate and current data layers on impervious cover, sewer and storm drain infrastructure, the drainage network, storm-water outfalls, storm-water hotspots and industrial storm-water NPDES sites, open space, natural area remnants and others important features. A smart watershed program commits to regularly maintain the GIS system, and make it accessible to residents and watershed groups.

Program 3

Rapid Assessment of Stream Corridors. A smart watershed program conducts a rapid assessment its stream corridors on a subwatershed basis, with the goal of completely assessing all stream and channel miles within a three year period. In addition, a smart watershed program uses the assessment data to correct existing problems and construct stream restoration projects, in accordance with goals and resources for the subwatershed plan.

Program 4

Water Quality Monitoring and Reporting. A smart watershed program takes a comprehensive approach to monitoring to support the implementation of subwatershed restoration plans, by selecting key watershed indicators, sampling to prioritize water quality problems in subwatersheds and conducting basic detective work to isolate pollution source areas. In addition, a smart watershed program provides timely reporting of spills, untreated wastewater discharges and monitoring data to the public. Lastly, a smart watershed program promptly notifies the public in the event that it is unsafe to swim, contact water or consume fish tissue in local waters.

Program 5

Financing for Watershed Restoration. Smart watershed programs utilize a diverse blend of resources to finance watershed restoration, including capital budgets, storm-water utilities, fee-in-lieu for redevelopment projects, and state and federal grants and loans, to ensure they have the staff and resources to meet their 16 smart watershed programs.

Program 6

Inventory and Management of Natural Area Remnants. A smart watershed program carefully inventories the remaining natural areas in a subwatershed, and evaluates how remnant areas are being impacted by adjacent and upstream development. The program has an ongoing commitment to actively manage and restore priority remnant areas.

Program 7

Inventory of Watershed Retrofit Opportunities. A smart watershed program progressively evaluates the potential for retrofit opportunities within all of its subwatersheds. The program often sets a numerical target to guide implementation over many years (e.g. it commits to following the three stages of retrofitting in ten percent of its total watershed area within a five-year period.)

Program 8

Implement Stream Restoration Projects. Utilize appropriate stream restoration techniques within the context of subwatershed management plan. A smart watershed program uses stream assessment data to correct existing problems and install stream restoration practices in accordance with the goals and habitat objectives of the subwatershed plan.

Program 9

Watershed and Community Forestry. Smart watersheds programs directly link urban forestry with watershed restoration, with the goal of increasing healthy tree cover in the watershed. Smart watershed programs urban forests in public right of ways, vacant lands, parks, neighborhoods, schools and riparian areas. In addition, smart watersheds programs promote native species and provide guidance and criteria for tree planting and forest maintenance to the community.

Program 10

Eliminate Untreated Wastewater Discharges. A smart watershed program commits to an ongoing program to detect and eliminate any discharges of untreated wastewater into the watershed., including CSOs, SSOs, and illicit or illegal discharges.

Program 11

Land Reclamation on Municipal Lands and Parks. Smart watershed programs actively promote land reclamation on appropriate public lands to prepare these sites for reforestation, rain gardens, gardens and other community landscaping projects. As part of the land reclamation process, compost from recycled yard waste may be applied amend the soil at these sites. For example, a municipality commits to divert 10 percent of its annual yard waste stream for land reclamation on public lands.

Program 12

Demonstrate smart site practice on municipal development projects. A smart watershed program leads by example by implementing smart site practices on some of its own construction project. By experimenting with innovative technology and design, municipalities can help demonstrate and gain wider acceptance of smart site practices. For example, a municipality might incorporate smart site practices on two capital projects each year, and undertakes a monitoring program to quantify their benefits. Lastly, smart watershed programs link subsidies and incentives that promote growth to the use of "smart site practices" for individual redevelopment projects.

Program 13

Watershed Education. Smart watershed programs craft and implement effective watershed education programs. They focus on key pollutants or behaviors, carefully target their audiences, and choose a mix of media to spread their message. Smart watershed programs also survey their residents to understand their attitudes, and to measure the impact of their campaigns.

Program 14

Public Involvement and Neighborhood Consultation. A smart watershed program provides meaningful opportunities for public involvement and participation in each stage of subwatershed planning, and ensures that neighborhoods are fully consulted about adjacent restoration projects. Smart watershed programs also support and partner with local watershed organizations that are the best grass roots link to the community.

Program 15

Pollution Prevention for Hotspot Businesses. Smart watershed programs target the major hotspot businesses within their watershed for intensive and continuous training on how they can prevent pollutants from being exposed to rainwater or runoff. Smart watershed programs provide clear and compelling material on simple pollution prevention techniques, and recognize participating businesses that participate in these programs. In addition, municipalities demonstrate pollution prevention techniques on hotspot areas they own or control, and provide regular liaison with industrial facilities that are required to have a NPDES storm-water discharge permit and pollution prevention plan.

Program 16

Provide operation training for municipal and utility employees on urban source control. A smart watershed program commits to integrating pollution prevention in its daily operations, through continuous training of its employees and contractors in the following areas: street sweeping, fleet operations, leaf and yard waste collection, park and golf course management, trash removal/recycling, snow removal and disposal, facility maintenance, catch basin cleaning, sewer maintenance, water conservation, dumping/littering enforcement and road salting A smart watershed program designs a pollution prevention strategy for each of the operational areas described above, and designates a lead local agency to implement the operational training.

Program 17

Direct Assistance in Personal Stewardship. A smart watershed program offers a range of direct services to help watershed residents do the right thing, and continuously strives to make every resident aware of these services, and offer them in the most accessible, convenient and easy manner possible. Some common services include regular household hazardous waste programs, updated oil recycling directories, free compost for soil amendments, incentives to install rain barrels on roof leaders, native trees for lawn reforestation, free lawn soil testing, advice on non-toxic ways to deal with pests.

2001-2003
Priorities Report
Chapter 4

CLIMATE CHANGE: IMPACTS IN THE GREAT LAKES BASIN

CHAPTER FOUR Climate Change: Impacts in the Great Lakes Basin

Contents

4.1 INTRODUCTION

The Great Lakes Water Quality Board

The *Great Lakes Water Quality Agreement* identifies the Great Lakes Water Quality Board as the principal advisor to the International Joint Commission on all issues related to the water quality of the Great Lakes System. The WQB investigated the impacts of climate change on the Great Lakes basin under the 2001-2003 priority dealing with climate change.

The Council of Great Lakes Research Managers

The Council of Great Lakes Research Managers (Council) coordinated activities on the 2001-2003 priority dealing with climate change with the Great Lakes Water Quality Board. It studied the interaction of ground water and surface water in the Great Lakes, which is an aspect of climate change that complimented other initiatives. The Council's 1999-2001 Priorities Report underscored the need for further research on the complex relationship between ground water, Great Lakes water levels and coastal wetlands. The Council reviewed the state of knowledge regarding the effects of changing land use, the relationship of ground water and ecosystems, estimates of consumptive use, and discharge/recharge of ground water. That report made recommendations to the IJC regarding critical research needed to better understand ground water issues.

Recognizing that climate change may also be an important factor to consider in ground water quality and quantity, the Council built on this previous work and during the 2001-2003 biennial cycle, conducted a review of the state of knowledge about the potential impact of climate change on ground water quality and quantity in the Great Lakes basin.

Background work to identify research needs was accomplished by utilizing resources obtained through Environment Canada's Science Horizons program. This program offers recent post-secondary graduate scientists hands-on experience working on environmental projects under the mentorship and coaching of experienced scientists and program managers. A literature review was conducted and material compiled from experts who participated in the source water workshop held during the Montreal Public Forum in 2001. Workshop sessions on ground water indicators were organized at the 2002 State of the Lakes Ecosystem Conference in Cleveland, Ohio providing an excellent forum for the exchange of ideas.

The Council wishes to thank Cheryl Martin for compiling this report and to recognize the input of Douglas Dodge, Harvey Shear, Jim Nicholas, Doug Alley and all those who participated in the SOLEC 2002 sessions for helping the Council to identify research needs associated with this important issue.

4.2 CLIMATE CHANGE - ADDRESSING IMPACTS IN THE GREAT LAKES BASIN

Climate provides fundamental limits on, and oppor tunities for human activities and ecosystem func tioning. A change in climate could lead to alterations and impacts on:

- the frequency and severity of droughts and floods;
- surface and ground water quantity and supply;
- air, soil, sediment, and water quality;
- human health;
- ecosystem health and functioning;
- resource use and the economy, including agriculture, forestry, the fishery, recreation, tourism, energy, transportation, and manufacturing; and
- the "built" environment, including sewer and treatment plant capacity.

Numerous stresses already challenge the Great Lakes -- land use changes, chemical contamination, nutrient over-enrichment, alien invasive species, and acid precipitation. Climate change is yet another agent, acting in concert with other stresses.

The magnitude of changes presently occurring in our climate raises questions about the extent of their impact and our ability to adapt. The IJC is concerned about the impact of climate change and variability for the Great Lakes region and its residents, in particular, achievement of beneficial uses given in Annex 2 of the Great Lakes Water Quality Agreement. The IJC asked its Great Lakes Water Quality Board (WQB) to provide advice about implications and impacts of climate change on Great Lakes water quality and beneficial uses, and how we can address changes.

To provide insight into the issues and impacts associated with climate change in the Great Lakes region, the options available to address those impacts, and the challenges associated with taking action, the WQB commissioned a white paper, *Climate Change and Water Quality in the Great Lakes Region: Risks, Opportunities, and Responses*. The white paper addressed four key questions:

- What are the Great Lakes water quality issues associated with climate change?
- What are potential impacts of climate change on beneficial uses?
- How might impacts vary across the Great Lakes region?
- What are the implications for decision making?

To confirm the scientific and technical basis that characterizes and underpins the conclusions and findings, the white paper was subjected to external review. In addition, to ensure that the WQB had properly characterized the consequences of climate change, appreciated the challenges for taking action, and could provide sound advice to address impacts, the findings presented in the white paper were "ground-truthed" at a stakeholder workshop held May 28-29, 2003. The white paper, revised in light of the external review and the contributions from workshop participants, constitutes a separate report to the IJC. That report also presents the WQB's findings and advice.

Based on its findings to date, the WQB will continue its investigation of selected aspects of the climate change issue during the IJC's 2003-05 priority cycle.

Report of the Council of Great Lakes Research Managers

4.3 CLIMATE CHANGE – UNDERSTANDING THE IMPACT OF CLIMATE CHANGE ON GROUND WATER

4.3.1 Introduction

The drainage basin of the five Great Lakes covers an area of 750,000 square kilometers, including almost all of southern Ontario, some of northern Ontario, and much of eight U.S. Great Lake states. Within this drainage basin water from precipitation percolates through the soil and is stored as ground water. Recent estimations indicate that the volume of ground water stored in the Great Lakes basin is approximately equal to that of Lake Michigan (Grannemann *et al.* 2000). This ground water moves slowly, discharging into streams, wetlands and eventually to the Grea Lakes. On average, the lakes receive recharge waters from tributaries of roughly 3000 m3/sec from the U.S. side and 2300 m3/sec from the Canadian side (IJC 1993). Approximately 50 percent of that recharge may be indirectly contributed by ground water (Grannemann *et al.* 2000).

4.3.2 Stresses on Ground Water Supplies in the Great Lakes Basin

As population continues to grow in the Great Lakes basin, stresses on freshwater supplies also increase. Given that 39 percent of the Great Lakes basin population uses ground water as their source for drinking water (IJC 1993), it is clear that ground water sources need to be valued and protected both locally and regionally. More importantly, 90 percent of the rural population of Ontario relies solely on ground water to supply their residential needs (Piggott *et al.* Unpublished Paper), thus protection of this life resource is exceedingly necessary.

As population continues to grow in the Great Lakes basin, stresses on freshwater supplies also increase. Given that 39 percent of the Great Lakes basin population uses ground water as their source for drinking water (IJC 1993), it is clear that ground water sources need to be valued and protected both locally and regionally.

In recent years, the levels of the lakes have been declining, as drought and warmer winters have taken their toll. The lakes have dropped to their lowest point in 35 years (U.S. Water News Online 2002). This reduction in water availability, added to the fact that many of our aquifers are being stressed by pumping, may result in an inadequate supply of ground water in some areas. Ground water levels in some aquifers have declined over large areas, such as the aquifers outside Chicago, Illinois, near Milwaukee and Fox River-Green Bay, Wisconsin, and near Toledo, Ohio (Grannemann *et al.* 2000). Total ground water withdrawal in the Great Lakes region in 1995 was estimated to be 1,510 million gallons per day (Solely *et al.* 1998). Growing populations and increasing demands on ground water supplies create an ever increasing risk of depleting ground water supplies beyond rechargeable levels.

4.3.3 Climate Change Models

General Circulation Models

General Circulation Models are computer programs created to mimic the interactions of the atmosphere and land surface in producing weather and climate conditions. Newer General Circulation Models often include an ocean component to account for the oceans ability to moderate temperatures and to hold carbon dioxide. They are used to investigate the influence of possible climate forcing mechanisms, like increasing levels of CO2, and to suggest past and future climates.

The use of General Circulation Models is limited by several factors. First, our knowledge of the complex interactions within the climate system restricts the function of the models. Since we do not know all of the variables, we cannot account for them in our models. Second, because General Circulation Models are designed to work over a large-scale area, they do not account for small but significant regional features. The Great Lakes are not represented in many of the General Circulation Models, thus their affects are not included in the simulations. Third, energy and moisture flow are averaged, not accurately representing the processes. This can result in misrepresentations in precipitation within the predictions.

In determining the usefulness of the General Circulation Models, the U.S. National Assessment of the Potential Consequences of Climate Variability and Change compared

Table 1
Predictions for the Great Lakes Region

	Hadley Centre Model	Canadian Model
Temperature change by 2030	+1.2oC (Lake Superior)	+2.0oC (Lake Superior)
Temperature change by 2090	+2.9oC (Lake Superior)	+5.4oC (Lake Superior)
Precipitation -summer	Slight decrease	0-20% decrease
Precipitation -winter	Slight increase	0-20% increase
Annual precipitation	Increase	Increase
Runoff	1-10% increase	10-12% decrease
Soil Moisture	Increase	20-40% decrease
Evaporation	Slight increase	Increase

(Frederick and Gleick, GCSI and the Meteorological Service of Canada, 1999; Legates 2002; 1995 Lofgren *et al.,* 2002b)

the two most commonly used General Circulation Models, the Hadley and Canadian models. The conditions used were the same for both General Circulation Models, though they were not reported in the literature. Although similar in purpose and methodology, the two models produce somewhat different results for the Great Lakes area. While both predict a slight temperature increase and agree that evaporation is likely to decrease, they do not agree on the direction of precipitation change, runoff or the effect on ground water (See Table and Figure 1).

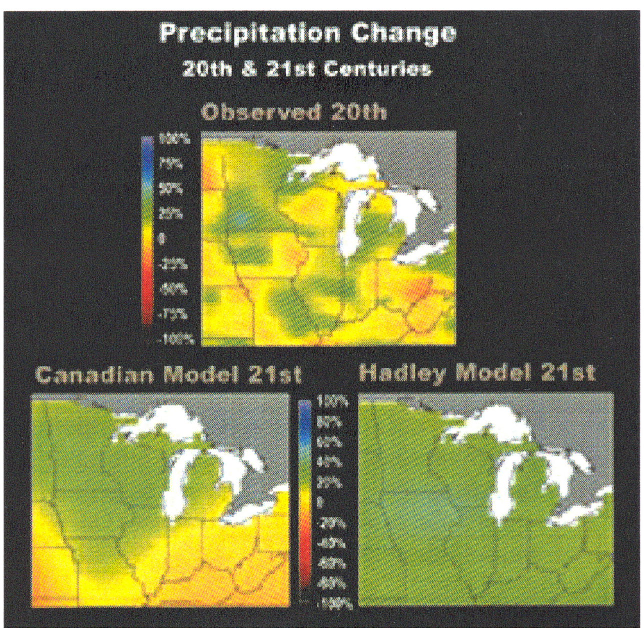

FIGURE 1
Comparison between present precipitation and future projections using the Canadian and Hadley models
(Adams and Gleick, 2000)

The comparison between the Hadley and Canadian models also includes runs to evaluate the ability of the models to simulate past and present climates. The National Oceanic and Atmospheric Administration and the Great Lakes Environmental Research Laboratory have conducted trial runs of the 1961 to 1990 base period and compared the results to observed mean temperatures. The Canadian model showed a strong cold bias during the winter and spring, and a warm bias over the fall and summer for the Lake Superior area. Predicted averages showed differences of up to five degrees Celsius in daily minimum temperatures. The Hadley model showed a warm bias during the winter and early spring, and was not able to predict an adequate range of daily maximum and minimum temperatures in the summer. However, the Hadley model showed biases usually less than three degrees Celsius.

Precipitation patterns also were predicted for the 1961 to 1990 run. The Hadley model proved better at duplicating early summer and late fall observations in precipitation, however, it did produce overestimates in late winter and spring, and underestimates in late summer and early winter. The Canadian model produces an estimate of summer precipitation that greatly exceeds the observed values and a small underestimate for fall and early winter. Overall, the Hadley model provides a more accurate representation of the observed precipitation averages.

The results of the trial run show that neither model is a completely accurate predictor of average temperature or precipitation. Still, differences in the models may be able to account for the different biases. The Hadley model exhibited a smaller bias overall, and this may be due to the crude representation of the Great Lakes in the model. It uses 3 grid cells to represent the Great Lakes, whereas the Canadian model has no representation of the lakes at all

(Croley and Luukkonen, 2002). The absence of the Great Lakes in the Canadian model and the representation of the Great Lakes area as a continuous land surface could lead the model to predict more convective precipitation in the summer and omit the effect of lake-effect precipitation in the winter (Lofgren *et al.* 2002a). On the other hand, it has been criticized that this could not be the only reason for the differences in predictions, as there have been differences of similar extent in the two models elsewhere in North America.

Regional Climate Models

Regional Climate Models were developed to account for the omission of regional land forms in General Circulation Models. By scaling down the grid area to typically 50 km, as compared to 300 km in a General Circulation Model, the Regional Climate Model can better predict regional climate changes (Hadley Centre 2001). Once known as Limited Area Models, Regional Climate Models do a much better job of simulating convection processes, which typically occur on the scale of a few kilometres. As convection is the mechanism responsible for most summer precipitation and severe storm weather, these smaller scale models should be more accurate at predicting summer precipitation, an area where General Circulation Models are very inefficient. Regional Climate Models are nested into an existing General Circulation Model and the predictions for a certain climate scenario generated by the General Circulation Model are the input data for the Regional Climate Model. Problems with this method are obvious, as miscalculations and mistakes in the predictions from the General Circulation Model are amplified within the Regional Climate Model. However, these problems are overlooked, as the purpose is to simulate climate processes influenced by regional land forms like the Great Lakes.

Results of the Canadian Regional Climate Model simulations are not available at this time however; initial trial runs from another regional model have seen valuable results. Observations from a 10 day and 24 month period correlated well with results from separate model runs using input data from documented weather reports. By using an Regional Climate Model rather than a General Circulation Model, the changes in lake surface temperatures and ice cover were replicated rather well. Important feedback cycles between land, lake and atmosphere were simulated at the finer scale, allowing the model to closely predict a similar climate to the observed conditions (Goyette *et al.* 2000).

Regional Climate Models have proven to be particularly good at simulating the interactions between lake, land and atmosphere to produce predictions of lake-effect precipitation. As lake effect snowfall accounts for about 30 to 50 percent of all snowfall in the Great Lakes (Goyette *et al.* 2000), the ability of the Regional Climate Models to simulate this is very important. During a simulation of one 10 day period in December 1985, the model was able to basically reproduce the distribution of lake-effect precipitation over the Great Lakes basin (Bates *et al*, 2002). In the major snow belt areas, precipitation was under-forecast at all four model resolutions, but predictions became more accurate at finer resolutions (Bates *et al*, 2002). It is expected that with climate change there will be almost no change in the northernmost snow belts, but an approximately 50 percent decrease in the amount of lake-effect snow in southernmost belts (Kunkel *et al*, 2002).

The Hadley Centre in the United Kingdom has developed an Regional Climate Model, "Providing Regional Climates for Impact Studies" (PRECIS), which is now being offered free to developing countries. The advantage of this Regional Climate Model is that it can be run on a relatively inexpensive personal computer, as compared to the supercomputers required for General Circulation Models (Hadley Centre 2001). Each 30 year simulation takes about four to six months to complete. Simulations over the United Kingdom, South Africa and Japan have shown a better ability to match past precipitation averages, which increases confidence in the future success of this model (Hadley Centre 2001).

Most Importantly, Regional Climate Models can work with other models to predict climate changes other than temperature and precipitation. The PRECIS model has been developed to work with models to predict storm surges (Hadley Centre 2002b). Using an Regional Climate Model will give a better indication as to the frequency and intensity of future storm surges. Development of a hydrological model of ground water using Regional Climate Model inputs for the Great Lakes basin could suggest if ground water resources will increase or decrease as our climate changes.

Historical Analogues

Historical analogues, observations about the way climate has varied and changed in the past, are good indicators as to how climate may change in the future. By examining the climate record from the past, we can estimate variability and tell when an extreme is outside the range of the natural variability. To use historical analogues, one would choose warmer than average years from the historical record and see how the increases in temperature may have affected precipitation, drought conditions and crop growth. Historical analogues are a reliable way to discover the consequences of climatic change for any region where long-term records exist.

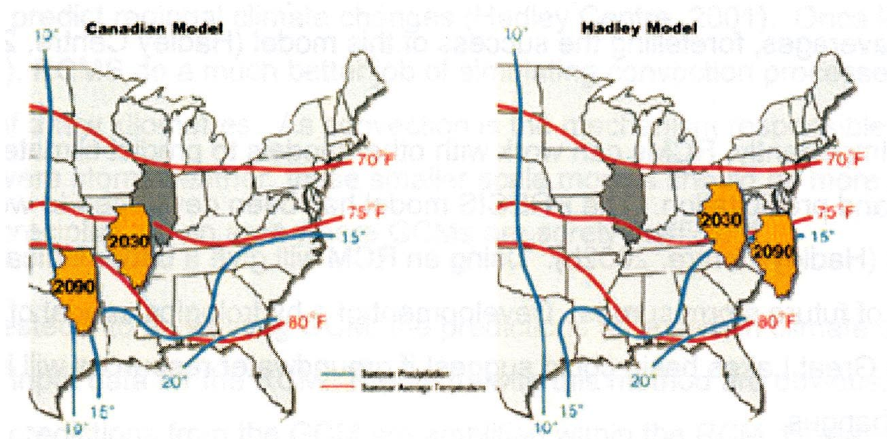

FIGURE 2
Projected climate in Illinois in 2030 and 2090 using Canadian and Hadley model projections
(Adams and Gleick, 2000)

Limitations of this method arise when there are only short-term records for a period of increased temperature. Drought conditions and higher temperature periods rarely last long enough to cause widespread changes in ground water levels and flow patterns. When this occurs, historical analogues may be used in conjunction with physically based scenarios like General Circulation Models, to predict climate changes.

Climate Transposition

Climate Transpositions or Spatial Analogues work on the principal that one may be able to predict future climate scenarios by looking at a similar climate in a warmer region nearby. Ideally, analogous locations will have similar topography, ecozones and land use however, this is rarely the case. For example, the climate of Toronto, Ontario has been predicted to resemble the climate of southern Ohio in the future (Government of Canada and U.S. EPA, 1995). However, Toronto is under the direct influence of the Great Lakes, whereas southern Ohio experiences a lesser moderating effect, being farther away from the Great Lakes. The effect of Lake Ontario on Toronto's climate cannot be accurately estimated, unless General Circulation Models or Regional Climate Models also are used.

Predictions from the Hadley and Canadian models have transposed the climate of Illinois, shown in Figure 2. The Canadian model predicts a more continental climate, much like the central U.S. The Hadley model shows a contrasting prediction, with Illinois having a more maritime climate similar to Massachusetts. Despite the differences in spatial transposition, it can be assumed that the climate of Illinois is going to get warmer, but we cannot tell if there will be more or less summer precipitation.

4.3.4 Urban Heat Islands

Changes in climate have been observed within cities due to the Urban Heat Island Effect and may be used to predict climate changes in other areas. Paved surfaces and building materials absorb, rather than reflect, the sun's heat, causing the temperature in the city core to rise. These core areas are often one to 10 degrees Fahrenheit (.56 to 5.6 Celsius) warmer than surrounding suburbs (Goddard Space Flight Center 2002). The additional heat rises, causing changes in air circulation and often forming rain clouds. This phenomenon has been documented in several large cities, such as Atlanta, where rainstorms were often produced downwind of the city.

Although small in nature, urban heat islands can be used in conjunction with other climate predicting methods to estimate changes in the hydrologic cycle, such as the amount and timing of precipitation.

In the past century there has been an increase in average annual temperature of 0.6 degrees Celsius. The 1990s were the warmest decade in the past 100 years, with seven of the ten warmest years occurring within this decade. However, the Great Lakes themselves have a significant influence over the climate; the large bodies of water are able to moderate temperature and influence wind and precipitation patterns on a regional scale. For this reason, the impacts of rising concentrations of CO_2 and other greenhouse gases on the climate patterns of the Great Lakes region are not so easily predicted. Moreover, without being able to predict changes to temperature and precipitation patterns, influences on ground water levels and recharge are unknown.

4.3.5 The Effect on Ground Water

Changes in temperature and precipitation resulting from climate change and variability will cause an alteration to the hydrologic cycle. The proposed increases in temperature will likely cause an increase in evaporation, decrease in runoff, and reduction in stream flow, all leading to a reduction in ground water recharge. The frequency of extreme weather events, such as thunderstorms, tornadoes

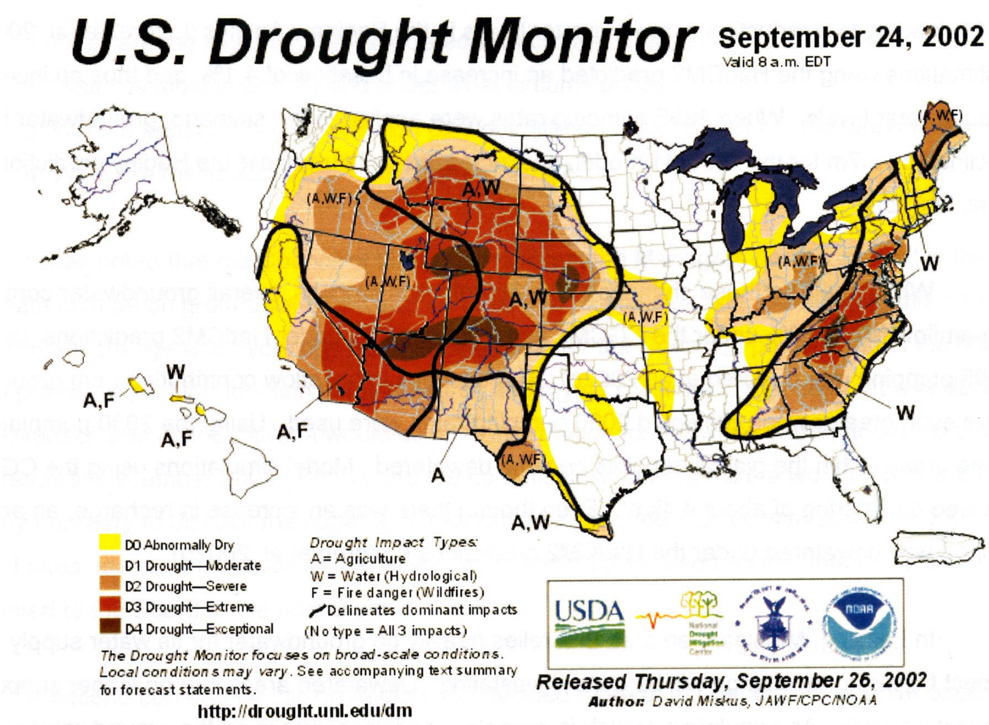

FIGURE 3
Drought conditions in the U.S. on September 24, 2002, after a summer of low precipitation and extremely high temperatures

and floods, are expected to increase (Prowse *et al*). These changes are amplified when human activities are considered. Higher temperatures and evaporation will lead to an increased need for irrigation for drier soils and lawns. Hotter summers will lead to an increased demand for electricity for air conditioning, causing more water to be withdrawn for cooling purposes and placing more pressure on declining ground water resources. Overall, an increase in summer water demand of five percent is predicted (Environment Canada 1995).

Increases in evaporation will reduce the amount of water infiltrating the soil and reaching the water table. An increase in temperature at the Experimental Lakes Area, north of the Great Lakes region, from 14 to16 degrees Celsius led to an increase in evaporation of 30 percent (Schindler 2001). On the southern Great Lakes, increases in evaporation are expected to result in drier soils, thus reducing runoff and ground water recharge (Environment Canada 1995). The predicted reduction in runoff would make ground water base flow an even more important component of stream flow.

Increases in ground water recharge are predicted for certain times of the year. Higher temperatures will alter the timing of snowmelt, causing ground water recharge to occur earlier in the spring. The ground would likely freeze at a later date, allowing early winter rains to penetrate the soil and recharge ground water supplies. The timing of recharge would shift to earlier in the spring and later into the winter, possibly compensating for the decrease in summer recharge. This recharge may be able to bring ground water back to "normal" levels, but due to the added stress from summertime withdrawal increases and increased evaporation, it may be too late to reverse the damage.

Many of the General Circulation Models and Regional Climate Models have predicted an increase in severe storms and extreme weather, possibly with more intense rainfall. This does not bode well for ground water recharge, as more of the water is likely to run straight into surface water courses instead of recharging aquifers. Infiltration can only occur at a set rate. If more rain falls than can be absorbed, most of it will run off, increasing the chances of flooding (United Nations Framework Convention on Climate Change 2002).

Additionally, the frequency of droughts is expected to increase, which could also contribute to ground water shortages. For the past two years, North America has experienced lower than average precipitation that has resulted in extreme drought conditions in parts of the continent. As seen in Figure 3, drought in the Great Lakes region has not been as devastating as in other regions, but the lack of precipitation and extremely high temperatures over the summer of 2002 have forced municipalities to issue water restrictions in most communities to conserve water. During drought conditions the soil is so dry it becomes hydrophobic and will not absorb the rainwater easily. If the frequency or intensity of droughts increases, as is expected with climate change, we will see a reduction in

Population growth is expected, which will place additional stress on the ground water supply and will add to the effects on ground water from climate change, therefore a larger decline in ground water levels and significant dewatered areas can be expected.

ground water recharge and declining ground water levels. The quality of ground water may be degraded by falling levels and slow recharge. High intensity rainfall is more likely to wash contaminants into surface water sources as overland flow rather than allow gentle infiltration down to the water table. However, if withdrawals increase, and recharge decreases, the amount of the ground water in an aquifer will decrease, possibly concentrating the contaminants that may be within it. Because we are unsure as to how precipitation will change, it is still unclear whether climate change will have a significant effect on ground water contamination (Adams and Gleick, 2000).

An evaluation of the effect of climate change on ground water resources in the Lansing, Michigan area was made by U.S. National Oceanic and Atmospheric Administration and the Great Lakes Environmental Research Laboratory using the Hadley Centre Model and the Canadian Model. A combination of a lake-evaporation model and a runoff model was used to estimate stream flow, which was then used to input into a ground water flow model. Results from this process would amplify any mistakes, as results from each model were used as inputs for the next step.

In terms of ground water, the Canadian model predicted a reduction in ground water levels in the Saginaw Aquifer leading to a 19.7 percent decrease in base flow to streams in 2030 (Lofgren *et al*. 2002b). Estimations using the Hadley model predicted an increase in ground water levels and an increase in base flow of 4.1 percent. When 1995 pumping rates were applied to the scenario, ground water levels declined by 2.7 meters for the Canadian model, and increased by 0.1 meter under the Hadley predictions (Lofgren *et al*. 2002b).

When applying these changes to the hydrological process, overall ground water contribution to stream flow fell by 32 percent under the Canadian model and increased 6 percent under the Hadley model predictions, using the 1995 pumping rate (Lofgren *et al*. 2002b). The changes in base flow contribution from ground water were even greater when using projected 2030 pumping rates. Using the 2030 pumping rates, some areas within the glacial deposits became dewatered. Model simulations using the Canadian models showed dewatering of about 4.4 km2 within this watershed. Even though there was an increase in recharge, an area of about 0.5 km2 was dewatered under the Hadley model predictions (Lofgren *et al*. 2002b).

Any reductions in stream base flow as a result of climate change will have severe implications for ground water dependant species, such as brook trout, some species of lungless salamanders, and other plants and animals. Brook trout require ground water upwellings to spawn and for fry to grow and hatch, whereas the salamanders need cool, wet ground water seepage areas to complete their life cycle. Without these ground water discharges, the communities in which brook trout and lungless salamanders live will see drastic alterations in community balance.

Areas that rely heavily on ground water for their water supply may be significantly affected by climate change. Dewatered areas can no longer support wells for domestic supply. Population growth is expected, which will place additional stress on the ground water supply and will add to the effects on ground water from climate change, therefore a larger decline in ground water levels and significant dewatered areas can be expected.

4.3.6 Recommendations

The Council recommends the following to the IJC.

- **Recommend to the Parties that research funding be directed to the following areas related to the impact of climate change on sources of ground water in the Great Lakes basin.**

1. **Examine historical data to determine how climate changes have affected ground water quality and quantity, to identify linkages between ground water and species/community distribution, to understand temporal and spatial variability and to assess how physical alterations of the land surface affect ground water recharge.**

2. **Improve Regional Climate Models and make them accurate for smaller scales so as to understand linkages to ground water and runoff at scales of interest.**

3. **Maintain or increase regional and national monitoring of hydrologic information, assess aquifer extent, ground water availability and the impact of climate change on recharge and evapotranspiration.**

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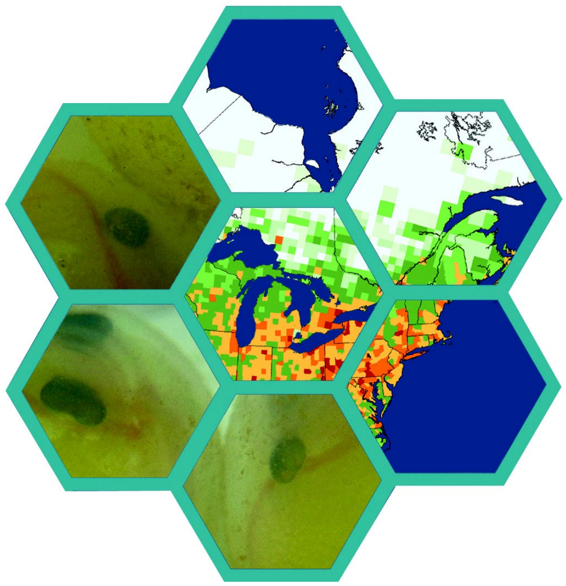

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Chapter 5

EMERGING GREAT LAKES ISSUES IN THE 21ST CENTURY

CHAPTER FIVE Emerging Great Lakes Issues in the 21st Century

Contents

Report of the Great Lakes Science Advisory Board

5.1 INTRODUCTION

The scope of the Great Lakes Science Advisory Board's (SAB) work also extends to the scientific dimensions of "emerging issues"; a term that includes issues that are new arrivals on the public policy agenda as well as those that are established, but changing in substance, scope or significance. The centerpiece of this priority activity in the 2001-2003 biennium was the conduct of an "expert consultation" in partnership with other *Great Lakes Water Quality Agreement* institutions of the IJC (the Great Lakes Water Quality Board, Council of Great Lakes Research Managers, and International Air Quality Advisory Board), Environment Canada, the U.S. Environmental Protection Agency, and The Johnson Foundation. Objectives included a scoping exercise to identify issues of importance under the *Great Lakes Water Quality Agreement* over the next 25 years; binational discourse among eminent U.S. and Canadian scientists; and the identification of specific initiatives to ensure progress under the *Great Lakes Water Quality Agreement*. Topics to guide discussion included new non-chemical stressors, new chemicals, new effects, changing ecology of the Great Lakes, and new policies.

Toward that end, several overarching recommendations were generated that are of critical importance if a science-based approach to implementation of the *Great Lakes Water Quality Agreement* is desired. The *Great Lakes Water Quality Agreement* must be reviewed in a comprehensive manner and with an eye toward revisions that will allow it to reflect a current vision of goals, priorities and institutional arrangements.

A significant outcome of the expert consultation was recognition of the policy and institutional dimensions of emerging issues. Research, monitoring and data analysis needs associated with the identification of emerging issues were documented, but it also was noted that science can only be effective when conducted via institutional arrangements that encouraged its application in the decision-making process. **Toward that end, several overarching recommendations were generated that are of critical importance if a science-based approach to implementation of the *Great Lakes Water Quality Agreement* is desired. The *Great Lakes Water Quality Agreement* must be reviewed in a comprehensive manner and with an eye toward revisions that will allow it to reflect a current vision of goals, priorities and institutional arrangements.**

Great Lakes Water Quality Agreement implementation requires a greater degree of accountability, benchmarks for measuring progress and an aggressive implementation schedule that reflects the urgency of basin ecosystem restoration and protection efforts. As well, the need for a binational, science-based decision support system with requisite monitoring and information/data management components; and new/revised institutional mechanisms that move the notion of an "ecosystem approach" to water quality from concept to reality by integrating governance responsibilities for air, land and water management across all relevant levels of government.

5.2 EXPERT CONSULTATION ON EMERGING ISSUES IN THE GREAT LAKES IN THE 21ST CENTURY

5.2.1 Background

In its 1999-2001 Priorities Report, the SAB recommended that the IJC support a specific initiative related to emerging issues in order to comprehensively identify and review emerging issues as a priority activity. The biennial priorities approved by the Commission for 2001-2003 included a provision to hold such a meeting. The substantial interest of other IJC advisory groups lead to a collaborative planning effort involving the Great Lakes Water Quality Board, International Air Quality Advisory Board and Council of Great Lakes Research Managers. These IJC advisory boards then formed a partnership with Environment Canada, U.S. EPA and the Johnson Foundation to convene an expert consultation at Wingspread, February 5 - 7, 2003. The planning committee identified three principle objectives to be achieved in the consultation process:

- to conduct a scoping exercise to identify issues of importance for the Great Lakes over the next 25 years as part of the advisory roles of the IJC boards;
- to facilitate binational discourse on an interdisciplinary basis among eminent scientists and policy makers; and
- to identify specific initiatives that represent the most promising future opportunities for sustaining progress under the *Great Lakes Water Quality Agreement*.

The format chosen for the Expert Consultation was carefully crafted to maximize discussion and interaction. A set of six themes was selected to explore a range of future issues and challenges for the Great Lakes. The presentations associated with each theme were deliberately kept to a combined total of 30 minutes so that there were would be significant discussion time, which was managed by a professional facilitator.

The Wingspread facility proved to be highly conducive for both informal and formal discourse, and allowed participants to more easily put aside any biases from their day-to-day environments. The participants were carefully chosen to provide diversity of both experience and expertise, and included scientists and decision makers from federal agencies, academia, industry, and consulting, as well as with interests both within and outside the Great Lakes basin.

It is anticipated that the full proceedings of the Expert Consultation will be published in a peer-reviewed journal in due course.

5.2.2 Themes of discussion

Visioning Statement: State of the Great Lakes 2025

There are many different processes that can be used to develop a vision of the future and create a workshop atmosphere conducive to sharing new thoughts. The introductory session used the metaphor "Retreat of the Industrial Glacier" to capture the impact of contemporary urban philosophy and design that is connecting the built and natural environments in cities throughout North America. The abandonment of industrial waterfront sites is providing a unique opportunity to provide natural areas and amenities, often in the very heart of the central core of the urban area. These efforts are being supported by other related concepts, such as "green design principles" and "green building construction" that taken together represent a new development paradigm having a major positive impact for Great Lakes cities over the next 25 years and beyond.

If the prospects for greater coexistence for city and nature are to be beneficial in terms of maintaining and restoring the integrity of Great Lakes waters, it will be critical to include Great Lakes goals within an intergovernmental framework that encompasses the basin ecosystem in the decision-making process at all levels of government.

To ensure that costly restoration efforts in urban areas are sustainable, new investments of research in aquatic science need to be made to provide a greater understanding of ecosystem function. In terms of the impact of development, the effects of imperviousness, both in terms of habitat fragmentation and increased runoff, merit special research focus. There is also a need for greater political awareness that the watershed is not merely a section of shoreline with aesthetic value, but is an extensive biodiverse environment that has fundamental requirements for maintenance and health.

New Non-Chemical Stressors

The major non-chemical stressors currently known to be impinging on the Great Lakes basin ecosystem -- invasive species, climate variability, nutrient enrichment, habitat loss, and food web dynamics -- will continue to affect Great Lakes water quality in the future. The relevance of these ongoing issues underscores their intractability and the

scientific challenge of addressing them. For example, the issue of invasive species is not new, but it has been accelerating in recent years because of globalization and the vulnerability of the Great Lakes to invasions. The current number of known invaders stands at 162, with many more "surprises" anticipated as long as effective action is not taken. The ultimate non-chemical stressor is the economy, since all stressors result from human economic activity.

In terms of ecosystem science, the most critical factors dominating ecological processes in the Great Lakes originate from offshore in the open waters. Understanding the interconnections between physical, biological and chemical processes is the key to implementing a science-based approach to decision-making to achieve long-term management goals for large complex systems. A major challenge is the limitations imposed by the current institutional structures to implement the *Great Lakes Water Quality Agreement*, and to provide integrative management and oversight based on its goals.

New Chemicals

Substantial progress has been made over the past few decades in reducing or eliminating releases of critical pollutants identified under the *Great Lakes Water Quality Agreement* and achieving reductions in the ecosystem. While these trends are encouraging, other classes of chemicals are emerging as potential pollutants in the basin. The Existing Substance Inventories of the United States and Canada are approximately 80,000 and 25,000 substances, respectively, many of which have had no formal assessment of risk to human health and the environment and may be present in very low levels in both environmental media and biota. There are two major activities relevant to the identification of new chemicals of interest -- release inventories and evaluation of substances using models based on Quantitative Structure Activity Relationships.

Ongoing fish and wildlife research and ambient monitoring also has been effective in identifying new chemical classes in the Great Lakes. Polybrominated diphenyl ethers (PBDEs), perfluorosulfonates (PFOS) and carboxylates, chlorinated paraffins and naphthalenes, various pharmaceuticals and personal care products, phenolic substances and approximately 20 current-use pesticides have been identified.

New Effects

In the past, the identification of effects was largely based on a combination of field observation and scientific judgement by resource managers and biologists. New effects can be observed at different levels of biological organization ranging from the cellular to the ecosystem level, though most are first seen at the organism level. Systematic surveys are currently being undertaken in a limited way in the Great Lakes. They are limited in the sense that the studies are short term and selective in terms of species and localities. In the future, new techniques, such as toxicogenomics that combine disciplines - in this case Quantitative Structure Activity Relationships and toxicology potential - to enable predictive capabilities to be developed that will allow scientists to anticipate new effects on a more comprehensive basis.

The large surface area of the lakes makes them vulnerable to atmospheric deposition of chemical stressors, and the large volumes of the lakes may result in long residence times for these substances.

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Two central questions emerged from the discussions related to "how does one get ahead of the curve" with respect to effects? These can be summarized as:

- What is the appropriate balance between efforts to anticipate new effects and the further development of the knowledge and understanding of what is already known?
- What is the nature of the scientific commitment and program necessary to ensure that both countries are diligent in the identification of potential new effects as part of their overall goal of Great Lakes protection?

Changing Ecology of the Great Lakes

Ecosystems generally exhibit a resistance to change in the face of external perturbations – homeostasis. Yet, the Great Lakes have undergone tremendous ecological change in the past 200 years of human development within the basin and now scientists have come to "expect the unexpected." Human population growth and its impact have led to a great increase in the range and magnitude of stressors. These stressors include: nutrient loads, sediment loads, synthetic chemical loads, wetland destruction, microbial inputs, modification of thermal regimes, exotic species introductions, fish stocking and harvesting practices, and water withdrawals/diversions, among others. Despite their initial impact, reductions of the severity of these past stressors may explain the recovery conditions generally thought to prevail in the lakes.

Notwithstanding this recovery, the basin ecosystem has evolved well beyond its historic natural state. If the Great Lakes will never be returned to their pre-industrial state, what state or condition is achievable and acceptable? How will the *Great Lakes Water Quality Agreement* purpose to protect and maintain biological integrity be determined, if that condition is undefined? To answer these questions the U.S. and Canada needs a shared vision for the lakes that is supported by long-term management objectives. For example, more integrated binational approaches to water quality management, addressing such primary topics as nutrients, contaminants and land use, could be identified that would enable the ecosystem approach as perceived in the 1978 *Great Lakes Water Quality Agreement* to be fully realized. An example of a long-term management objective might be the reestablishment of locally extirpated top predators, as a prime indicator of sustainability.

New Policies

Policy approaches since the 1972 Great Lakes Water Quality Agreement have followed three distinct iterative approaches: the 1970s marked the adoption of the regulatory system, the 1980s introduced the concept of pollution prevention, and the 1990s was characterized by the integration of economy and environment decision making and the development of global protocols. Beginning in the late 1990s and continuing today, the emergence of the precautionary principle heralded a new policy approach, to address those instances where decision making cannot be supported by scientific certainty.

The areas of binational opportunity and importance for the Great Lakes region to be a policy leader are numerous. Several of the most prominent include: agricultural policy focusing on manure management and pesticide controls, control of alien invasive species, improved nutrient control, chemical emissions releases and landscape restoration. Yet despite this list, and the emerging importance of multilateral policies that are global in scope that have impact on the Great Lakes, there is no one institutional mechanism for policy development or consensus that is effective on a binational basis to address policy opportunities for the Great Lakes.

5.2.3 Future Challenges

One interesting outcome of the discussions was that no truly new, previously unidentified, threats to the Great Lakes emerged, perhaps suggesting that there are current mechanisms in place to adequately identify emerging issues, and that future problems of the Great Lakes will be continuations or permutations of those issues that we are already aware of. This could be primarily a result of our inability to adequately address these issues currently, or in the past.

While these topics are not new, there are some interesting "twists" to them that indeed make them important considerations for the future. The list of contaminants in the Great Lakes is a dynamic one, and not simply the IJC list of critical pollutants or the Tier I and Tier II substances from the Binational Toxics Strategy (Canada and U.S., 1997). Several new classes of chemicals have been identified by researchers to be present and persisting in the Great Lakes. As commerce changes, so do the chemicals in our environment. It is anticipated that we will continue to see new chemicals in the Great Lakes. It is noted that both Parties have programs in place to identify substances that may be released into the environment and that show persistent, bioaccumulative or toxic properties singly, or in combination.

Present chemicals as well as these new chemicals may exert new kinds of deleterious effects on fish, wildlife, and potentially also on humans. Researchers are reporting that many chemicals that were associated with the endpoints of mortality and population extirpations are now exhibiting subtle sub-lethal effects that are insidious and difficult to assess. For example, many compounds can impair or disrupt the endocrine system, interfering with proper development, reproduction and growth of certain species. Even more disconcerting is that fact that many of these effects do not exhibit a linear dose-response, so that declining concentrations of current chemicals may not always result in a decline of adverse effects. On the contrary, what is observed in some cases is the emergence of a new endpoint that was masked by a more evident effect caused by higher concentrations.

Inputs of nitrogen and phosphorus from point sources have been regulated for decades, but the loadings of nutrients from nonpoint sources still results in excess ambient water concentrations. Major sources of these nonpoint inputs are agricultural operations, both crop-based and animal-based. Runoff and animal manure disposal and treatment are not well regulated or controlled. In addition, nutrient cycling is not fully understood, as evidenced by the recent hypoxia trends in the Lake Erie central basin.

The majority of scientific opinion supports the concern that anthropogenic-induced climate change is affecting chemical, biological and physical aspects of the Great Lakes. Future effects that have been identified include the impact on lake levels. Another significant effect will be the impact of warming on biological community structure. Changes in either fish predator species or algal assemblages will further impact other trophic levels through top-down and bottom-up effects. Finally, warming of the Great Lakes will result in greater evaporation of semi-volatile compounds from the water column, which will accelerate the rate of leaching from sediment reservoirs to the water column.

The control of exotic species that have been introduced to the Great Lakes ecosystem have been and will continue to be a major challenge for resource managers and for Great Lakes communities. The current efforts to prevent further introductions have not been effective, however, as the current rate of new introductions is about two species per year.

Exotic species introductions often lead to changes in the biological community structure, and changes within the entire food web. These changes can cause instability in the overall ecosystem. Some changes have no clearly understood cause, such as the decline of *Diporeia* in all of the Great Lakes, with the exception of Lake Superior. Such stresses are anticipated in the future and may be due to combinations of stressors.

Finally, the impact of future increases in population and the growth of urban areas within the basin will inevitably lead to continued shoreline development, increased runoff, increased air pollution from increased vehicle distance traveled, energy demands, etc., and increased loss of fish and wildlife habitat including wetlands.

These future challenges are summarized below in terms of findings, which reflect important insights and discussion, and recommendations, which reflect specific initiatives and approaches.

5.2.4 Findings

Long-term objectives for recovery are necessary to achieve future progress in restoring and maintaining the chemical, physical and biological integrity of the waters of the Great Lakes basin ecosystem. The *Great Lakes Water Quality Agreement* should be reexamined in light of these objectives. The reestablishment of some native species could be one such objective - recognizing that many native species will have to be introduced and that restoring the Great Lakes to an historical natural ecosystem will not be possible.

Institutional effectiveness is impeded by a multitude of agencies and organizations fulfilling their own objectives with insufficient coordination, in the absence of shared long-term goals and strategies, and according to disparate visions.

A renewed sense of shared purpose is needed that delineates the image of the basin as a total system, that people accept collectively, and that has personal relevancy. No one vision of the Great Lakes may be attainable, or practical, because of the importance of this vast resource among many users. The challenge for the future will be to develop a process, or a forum, where shared values can be discussed, and decisions made to protect and maintain the high natural amenities that sustain the use and enjoyment of the resource. If expressed as a key question, it is “how do we organize ourselves to deliver an ecosystem approach?”

Greater integration is needed to address the tendency of the current practice of science and policy to be over-compartmentalized, with policy frequently lagging behind current scientific understanding. The goals and purpose of the *Great Lakes Water Quality Agreement* cannot be achieved until greater integration occurs, for example, in relation to policy decisions that affect the interface of land and water, or in the case of the environment and the economy.

Additional formal binational programs are necessary to contribute greater inter-operability to the institutional framework, building on examples such as International Air

Deposition Network and the Binational Toxics Strategy (Canada and U.S., 1997).

Greater institutional capacity to coordinate and integrate roles, responsibilities and decision making to provide greater accountability among all levels of government is required. Policy making in the future will increasingly depend upon on a hierarchy of global, continental, national and local initiatives employing a wide variety of principles, instruments, methodologies and processes.

Major reinvestments in scientific infrastructure for the basin are required to provide improved monitoring and more importantly, to develop a *capability for ecosystem forecasting*. Decisions that impinge on Great Lakes water quality cannot be made wisely on the basis of current information, especially due to its lack of integration. New technologies have the potential to attain forecasting capability through the innovation of continuous real time monitoring employing integrated observation and monitoring systems. Such capabilities hold major promise for managers and decision makers to "get ahead of the problem curve" and to be truly proactive. The identification of new effects requires *greatly enhanced monitoring, data sharing and ecosystem forecasting*. Greater access to data; better basin wide data management; and detailed basin-wide, *binational scientific assessments* are needed to interpret and coordinate effects based research that encompasses an ecosystem approach.

Superior data management to inform decision making and reduce scientific uncertainty of a decision will be required for future policy making. The model for this capability exists with Statistics Canada, whose singular role is to provide high quality information and interpreting the data for decision makers, while maintaining confidentiality. There is considerable merit in developing a binational institution to collect, store and manage high quality Great Lakes information to support agency policies and programs, as well as *Great Lakes Water Quality Agreement* activities.

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New chemicals of concern are being identified through the development of screening assessments using Quantitative Structure Activity Relationships, the use of release inventories to identify high production volume chemicals and advancements in analytical methodology and equipment have resulted in improved capabilities to identify new classes of chemicals of concern in the Great Lakes. However, exposure assessment and effective monitoring is still needed to evaluate the significance in terms of Great Lakes water quality. Analytical method development needs to keep pace with the identification of new substances.

An urban renaissance is underway based, in part, on the value of the water resource to impart the qualities of the natural environment within the developed area. A fundamental tenet of that renaissance is creating the conditions for the natural environment to reestablish itself in harmony with the built environment. Developed waterfronts present unique opportunities for this to occur, and especially to bring natural amenities into the core of the city. Encouragement and innovation at the site level is evident through the *adoption of green design concepts*, such as the Leadership in Energy and Design principles, which could comprise further opportunities for extension into broader policy principles at the basin level.

Three key Great Lakes policy challenges will be increasingly relevant over the next 25 years: *agricultural policy* will need to move beyond developing "farm nutrient management plans" to consider manure, primarily, as a waste to be managed rather than as a source of nutrients; *treated waste water* will need to be reused and recycled; and, finally, *environmental and economic considerations* must be better integrated into policy decisions.

Broader ecosystem based management strategies are needed in order to manage resources, such as the fishery, to maintain biodiversity and to support land-use decision making. Centers of biological organization such as the Biodiversity Investment Areas identified by State of the Lakes Ecosystem Conference, need to be vigorously protected and maintained. It is theorized that *the future ecology of the Great Lakes may be unpredictable because it is unstable*, based on the scientific understanding that a well-functioning ecosystem hierarchy has few surprises. Biological integrity, and how to achieve it, is not scientifically well defined or understood, however the importance of higher levels of organization to impart a stability and regulatory constraint on the entire system was further theorized. It was speculated that the loss of biological integrity of the Great Lakes was a critical aspect of a lack of ecosystem integrity and stability.

Introductions of alien invasive species urgently require the development of better science and technology *to identify and treat pathways to the lakes,* such as ballast water, and to manage undesirable introduced species. Invasive species are a characteristic of disturbed systems, with accessible aquatic environments such as the Great Lakes most vulnerable. Once introduced, invaders permanently change the ecosystem, and defy management.

5.2.5 Recommendations

The SAB recommends the following to the IJC.

- **Recommend that the Parties conduct a comprehensive review of the operation and effectiveness of the *Great Lakes Water Quality Agreement*, and seek public input, with a view to substantially revising it to reflect a current vision of water quality goals, priorities and institutional arrangements. Such a review should also consider greater accountability for implementation and for measuring progress, including a schedule of priority actions deemed essential to achieve important water quality goals.**

- **Recommend that the Parties develop an ecosystem forecasting capability within the auspices of a coherent binational monitoring, information and data management policy and infrastructure for the Great Lakes to inform management and decision making, and to provide for greater public accountability in reporting progress.**

- **Recommend that the Parties establish a binational Integrated Great Lakes Observing System as a key element of major reinvestment in Great Lakes scientific infrastructure and to provide high quality scientific information for policy decisions.**

- **Recommend that the Parties establish an "International Field Year for Great Lakes Research" as a special five-year program to improve the knowledge and understanding of the Great Lakes basin ecosystem.**

- **Ensure that the Parties:**
  - **provide for adequate bilateral mechanisms to identify and monitor previously undetected chemicals in the environment.**
  - **develop and implement strategies that use Quantitative Structure Activity Relationships to assist in the earlier identification of potential chemicals of concern.**
  - **increase their support of the development and validation of Quantitative Structure Activity Relationships to promote the cost effective use of chemical testing resources.**
  - **establish early notification processes between researchers and regulatory officials to minimize the possible injury to health and property as a result of the presence of new chemicals.**

- **Recommend that the Parties further develop binational institutional mechanisms to enhance bilateral cooperation and coordination for air, land and water management in order to implement a truly ecosystem approach for water quality management that involves local, state/provincial and federal governments.**

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GREAT LAKES WATER QUALITY BOARD

CHAPTER SIX Great Lakes Water Quality Board

Contents

6.1 INTRODUCTION

The Great Lakes Water Quality Agreement identifies the Great Lakes Water Quality Board (WQB) as the principal advisor to the International Joint Commission (IJC) on all issues related to the water quality of the Great Lakes system. To best utilize available resources and in the spirit of cooperation, the IJC establishes priorities through a biennial consultation process with its Water Quality Board, Science Advisory Board, International Air Quality Advisory Board, and Council of Great Lakes Research Managers and with opportunity for public comment. Upon approval, the IJC assigns priorities to one of these advisory boards, depending on the group's mandate and expertise. Many priorities provide opportunities for collaboration. Some priorities are designed for completion in two years; others are addressed for a longer term.

Consistent with its responsibility under the Great Lakes Water Quality Agreement, the WQB focussed on the following issues during 2001-03 biennial cycle:

- Climate change -- addressing impacts in the Great Lakes basin (Chapter 4)
- Annex 2 - Remedial Action Plans and Lakewide Management Plans (Chapter 2)
- Lake Erie ecosystem changes (Chapter 6)
- Botulism type E outbreak (Chapter 6)
- Great Lakes system navigation review (Chapter 6)

Lending their professional expertise, individual WQB members also contributed to priority work undertaken by other advisory boards, including urbanization and emerging issues.

6.2 LAKE ERIE ECOSYSTEM CHANGES AND BOTULISM TYPE E OUTBREAK

6.2.1 Background

In 1999, the U.S. Environmental Protection Agency (EPA) and the National Water Research Institute of Environ ment Canada independently reported two disturbing observations for Lake Erie -- the phosphorus concentration in the water column was increasing and dissolved oxygen depletion was continuing to be observed in the bottom waters of the central basin. The trends continued through at least 2001. The increased availability of the nutrient phosphorus and the potential for die off of living organisms as a result of oxygen starvation threatened a return to conditions that prevailed in the late 1960s and early 1970s, such as the presence of dead and rotting *Cladophora* and other plant life on beaches.

Other recent observations are the outbreaks of botulism among fish and birds in Lake Erie and the apparent spread to lakes Huron and Ontario. This too resulted in the littering of beaches and shorelines with rotting carcasses and caught the public's attention not only with regard to aesthetics, but also the potential threat to public health. Questions were raised as to what would constitute a necessary and sufficient program and policy response to both issues.

The Water Quality Board (WQB) had tracked both issues and, at its meeting in Ottawa, Ontario on October 8, 2002, decided to seek expert insight into what changes were occurring and why. Concurrently, the International Joint Commission (IJC) asked for advice so that it, in turn, could advise governments as to an appropriate course of action in terms of research, programs and policy. IJC Canadian Chairman Herb Gray received a preliminary briefing on the Lake Erie ecosystem change issue on November 14, 2002 and all Commissioners were briefed on both issues on December 3, 2002.

The WQB received a more extensive briefing from key researchers at its March 6-7, 2003 meeting. For the Lake Erie issue, the WQB received three presentations:

- *Background and Historical Context*. Glenn Warren, U.S. EPA
- *Lake Erie and the "Dead Zone."* Murray Charlton, National Water Research Institute
- *Lake Erie Trophic Status*. Jan Ciborowski, University of Windsor

For the botulism issue, the WQB received three presentations:

- *Type E Botulism Related to Fish Mortalities Along the New York Portion of Lake Erie.* Bill Culligan, New York Department of Environmental Conservation
- *Avian Botulism.* Grace McLaughlin, U.S. Geological Survey
- *Fish-Eating Bird Die-Offs -- The Ontario Experience.* Jeff Robinson, Environment Canada

6.2.2 Lake Erie Ecosystem Changes — Findings

The WQB presented the following findings and advice to the IJC on May 8, 2003.

The observations reported by U.S. EPA and Environment Canada in 1999 had also been seen by other scientists. Among other observations for Lake Erie were:

- Increased phosphorus concentrations in the open waters of the central basin, even though reported loadings of total phosphorus to the lake have not risen much.
- Very low phytoplankton biomass, as measured by chlorophyll *a* concentrations.
- Oxygen demand in the central basin has not changed.
- Earlier onset and increased persistence of the area of the hypolimnion of the central basin susceptible to reduced dissolved oxygen concentrations.

To determine why, a group of concerned and knowledgeable scientists formulated a series of questions, and U.S. EPA issued a call for research proposals. The Lake Erie Millennium Network, which had previously formulated research plans to evaluate the questions, submitted a framework for conducting the research. Also, in addition to their research, ongoing since the 1980s, Environment Canada pledged logistical support. The research was inaugurated in earnest in 2002 and data and findings are routinely shared as they become available. The current research is being conducted in light of the present understanding of the issues and is designed to test hypotheses and to establish or confirm causative linkages. The findings from the research, to be completed in late 2003, will be used to inform the program and policy decision-making

and to determine the direction of future research that may be required. The questions and preliminary findings to date are the following.

- Possible reasons for expecting reduced thickness and / or increased persistence of the hypolimnion:
- warmer than normal summers (warmer surface water)?
- longer than normal summers (more time for oxygen depletion)?
- greater heating due to clearer water?
- greater penetration by ultraviolet light (ozone depletion)?

- Possible limits on primary production (phytoplankton biomass):
- high grazing pressure (especially by zebra and quagga mussels)?
- nutrient limitations (phosphorus or nitrogen) in subsurface epilimnetic water?
- trace metal (iron or copper) limitations?
- ultraviolet light- and contaminant-induced inhibition?

- Increases in phosphorus loadings? Recent calculations suggest minimal increases from point sources; however, there is uncertainty associated with the loadings because of:
- reduced data for tributaries (the result of cutbacks in monitoring programs);
- higher (less sensitive) detection limits being used in reporting sewage treatment plant inputs; and
- unusually strong autumn storms in recent years, which could result in strong, unmeasured pulses of phosphorus, due to increased land runoff and / or erosion and resuspension of lake sediments.

- Food web disruption and increased rate of nutrient cycling or new pathways for cycling, because the presence of zebra mussels may have disrupted the food web?

A range of other data and findings will also be available and factored into the equation. To summarize preliminary findings:

- Weather conditions are playing a dominant role, both short and long term.
- There are strong blooms of phytoplankton in the epilimnion in the spring.
- The hypolimnion is biologically very active.
- There are dramatic changes in benthic processes in both shallow and deep waters.

Possible key drivers include:

- climate change;
- consequences of habitat degradation, for example, as a result of changes in land use, shoreline hardening, and wetlands; and
- alien invasive species.

Scientists are carefully exploring and considering the evidence to establish linkages and determine which are controlling or contributing factors to the observed changes in Lake Erie. Discussions took place at the Lake Erie Millennium Conference at the University of Windsor, Ontario on May 6-7 [and at the International Association for Great Lakes Research conference in Chicago, Illinois on June 22-26]. Conclusions and advice will be available late in 2003.

Another observation is that changes in Lake Erie began about 1996. Before that date, ecosystem quality was improving, as measured by phosphorus loadings and water concentrations, and the size of the anoxic zone. However, the changes were not recognized until 1999 in part because of natural spatial and temporal variability of the very dynamic Lake Erie ecosystem, the reduced and intermittent sampling and monitoring programs, and human nature (i.e. recent changes are most vivid).

Because of its natural characteristics, the central basin of Lake Erie has always experienced occasional anoxic problems, the severity of which is determined by the thickness of the hypolimnion. Weather -- temperature and storms -- determine the thickness. The size and persistence of the "dead zone" cannot be used to gauge the success or failure of phosphorus load reduction policies and programs introduced in the 1970s.

To illustrate by example the dynamic and sensitive nature of the Lake Erie ecosystem, after 1990, water clarity improved in the western basin, but blooms of blue green algae occurred. Summer phosphorus concentrations in the waters of the central and eastern basins appeared to decrease between 1990 and 1995, but then increase again. Such changes are not unidirectional but, rather, may reflect changes caused by the rapid development of, and subsequent fluctuations in the dreissenid mussel population.

A long-established measure of the trophic status of Lake Erie is hypolimnetic oxygen depletion, which can result in formation of an anoxic "dead zone." Although one should be concerned about changes in this important measure, the WQB was advised not to be alarmed by low dissolved oxygen levels. Because of its natural characteristics, the central basin of Lake Erie has always experienced occasional anoxic problems, the severity of which is determined by the thickness of the hypolimnion. Weather -- temperature and storms -- determine the thickness. The size and persistence of the "dead zone" cannot be used to gauge the success or failure of phosphorus load reduction policies and programs introduced in the 1970s. Those programs contributed to the elimination of anoxic conditions in shoreline areas and in the western basin of Lake Erie, and ameliorated the problem in the central basin. However, management of phosphorus loadings to achieve a state where anoxia never occurs in Lake Erie may not be a realistic goal.

The WQB notes that anoxia has also been documented in smaller inland lakes.

6.2.3 Botulism Type E Outbreak -- Findings

The bacterium *Clostridium botulinum* has been recognized as a major cause of mortality since the early 1900s. The bacterium is classified into seven types by the characteristics of the neurotoxin produced. Death is caused by ingestion of the toxin. Both Type C and Type E botulism are found naturally in anaerobic environments. Type C is found in waterfowl worldwide, and Type E is found in fish-eating birds in the Great Lakes. Spores can remain in the ecosystem for years and are quite resistant to temperature extremes and drying.

In the absence of oxygen, with a suitable nutrient source, and under favorable temperature and acidity conditions, spores can germinate and vegetative growth of bacterial cells can occur. Botulism toxin is produced only during vegetative growth. The etiology of botulism is well characterized, as are clinical signs of, and diagnostic tests for poisoning.

Recent Type E botulism outbreaks among fish in the Great Lakes were in southern Lake Huron (1998-99), western and central Lake Erie (1999-2000), eastern Lake Erie (2000-02), and Lake Ontario (2002). For eastern Lake Erie, a number of fish species have been affected as well as the benthic species, mudpuppy. In terms of both numbers of birds and species affected, the U.S. Geological Survey found that the largest outbreak of avian botulism occurred in eastern Lake Erie also in 2002, coincident with the outbreak among fish. Environment Canada has investigated botulism events along the north shore of eastern Lake Erie.

The state of New York has investigated the number and the timing of fish killed. Type E botulism has been present for a long time, but what is different now to trigger the massive outbreak? As part of their investigation for cause-effect relationships, the state has investigated recent ecosystem changes in eastern Lake Erie. These include declining productivity, increased water clarity (changes in fish distribution), and presence of alien invasive species (the dreissenids zebra and quagga mussels and round gobies). There appears to be a correlation of Type E botulism outbreaks with the presence and abundance of round gobies. Environment Canada has reported that naturally occurring but rapid changes in water temperature can cause fish die-offs which, with other factors, may lead to conditions conducive for an outbreak. The Type E botulism outbreaks are, however, most likely unrelated to the central basin hypolimnion anoxia issue.

The need for research on how the toxin moves through the food chain and why some species are affected so much, while other similar species are affected so little, is key to developing management and policy advice. Investigators recognize the critical roles played by the host for the bacterium, agents, and the environment. They are looking for clues to the source of the toxin and its transfer among gobies, zebra mussels, fish, fowl and maggots. Studies are under way to answer key questions:

- Where are the anoxic conditions that promote germination of the spores and subsequent production of the toxin?
- What is the key link to fish -- dreissenids or other invertebrates?
- What is the role of bottom sediments?
- Is the bacterium a strain native to the Great Lakes or an alien invasive species itself?

Studies are also under way to determine the risk posed by Type E botulism to human health. A potential pathway is consumption of fish, but risk can be minimized when fish are properly prepared. Fish which display symptoms of botulism should, of course, be avoided entirely.

6.2.4 Advice and Recommendations of the Great Lakes Water Quality Board

The Water Quality Board will continue to track both the Lake Erie and the Type E botulism issues. The WQB offers the following advice now.

The level of funding for research reflects the high level of commitment by the Parties to determine what changes are occurring in Lake Erie and, more importantly, why. The findings should help inform program and policy decisions. The WQB supports additional research that may be required, in light of findings from the present work.

The WQB recommends the following to the IJC:

- **Recommend that the Parties earmark adequate funding to support additional research required to characterize changes in Lake Erie and to inform program and policy decisions.**

The WQB is concerned about the uncertainty associated with phosphorus loadings to Lake Erie and, indeed, the other Great Lakes. Particularly uncertain are loadings associated with land runoff. This is the direct result of past cutbacks in surveillance and monitoring programs. As a result of those cutbacks, large portions of the drainage basin are unmonitored, and other portions are under-monitored, so that major events, such as storms, which contribute large amounts of nutrients and other contaminants, are not measured. There is a need to assess the level of support for watershed, tributary, and in-lake monitoring programs.

To protect environmental gains achieved to date, better track current issues, and identify emerging trends, **the WQB recommends the following to the IJC:**

- **Recommend that the two federal governments support core funding for a necessary and sufficient surveillance and monitoring program.**

The WQB is impressed by the high level of cooperation and timely information sharing among investigators for the Type E botulism issue. Such networking is essential to characterize issues and develop scientific information to inform program and policy decisions. The level of funding appears to be adequate at present for U.S.-based programs, but insufficient for Canadian work, as testing and monitoring compete for resources for other threats such as the West Nile virus. It is anticipated that U.S. programs will also face such funding competition. Continued funding for research also is required to answer key scientific questions.

The WQB recommends the following to the IJC:

- **Recommend that the U.S. and Canadian federal governments continue funding for investigative programs for Type E botulism that will inform policy and program decisions.**

The WQB notes the apparent link of alien invasive species to both the Lake Erie and the Type E botulism issues. In its previous advice in 2001, the WQB observed the environmental and economic consequences of alien invasive species, especially zebra and quagga mussels, and is concerned about future, potentially more devastating consequences, unless definitive action is taken now to protect the Great Lakes from future invasions. The WQB continues to express concern about the lack of progress to implement affective ballast water treatment.

6.3 GREAT LAKES SYSTEM NAVIGATION REVIEW

The U.S. Army Corps of Engineers initiated a navigation review of the Great Lakes system for several reasons, including a 1999 mandate by the U.S. Water Resources Development Act; increased trade and economic growth; the aging infrastructure of the St. Lawrence Seaway; and the continued economic importance of the Great Lakes region, especially in light of the limited capacity of the existing locks system to handle international shipping. The Corps released its draft *Great Lakes Navigation System, Reconnaissance Report* on April 24, 2002.

After review and revision, the report was approved on February 13, 2003 "as a basis for further study needed to support a [U.S.] Federal decision on whether to proceed with feasibility phase studies." However, prior to initiation of the feasibility study, it was concluded that further information was required to support a decision on whether to proceed. A supplement to the reconnaissance report will include an assessment of baseline conditions for the environment, engineering features, and economic conditions, as well as public involvement and coordination.

Concern has been expressed that changes to the infrastructure of the St. Lawrence Seaway system might adversely impact the environmental quality and integrity of the Great Lakes basin ecosystem.

In response to discussions between Canadian and U.S. officials, the two countries, on May 1, 2003 signed a "memorandum of cooperation to ensure the ongoing success of the Great Lakes and St. Lawrence Seaway." This arrangement will help the U.S. Department of Transportation and Transport Canada to collaborate on a comprehensive transportation study of the waterway, specifically to:

- "identify factors and trends affecting the domestic and international marine transportation industries.
- "assess current and future transportation requirements for the waterway.
- "evaluate the reliability and condition of the waterway, including the costs and benefits of maintaining the existing infrastructure.
- "assess the environmental, as well as the engineering and economic factors, associated with the current and future needs of the Great Lakes St. Lawrence Seaway system and the transportation infrastructure on which it depends."

The review will also require close cooperation with the U.S. Army Corps of Engineers, the Canadian St. Lawrence Seaway Management Corporation, and the U.S. Department of Transportation's St. Lawrence Seaway Development Corporation.

Concern has been expressed that changes to the infrastructure of the St. Lawrence Seaway system might adversely impact the environmental quality and integrity of the Great Lakes basin ecosystem. Among the environmental concerns are greater access by, and habitat for alien invasive species; increased exposure, dredging, and disposal of contaminated sediment; shoreline erosion; and changes in lake water levels which, in turn, could affect water temperature and fish habitat. The Water Quality Board is therefore tracking developments as the multi-year study proceeds, and will keep the IJC apprized of developments. The status of the study can be tracked through the web at: http://www.lre.usace.army.mil/glnav/index.htm.

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Chapter 7

GREAT LAKES SCIENCE ADVISORY BOARD

CHAPTER SEVEN Great Lakes Science Advisory Board

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7.1 INTRODUCTION

7.1.1 Background

The Great Lakes Science Advisory Board (SAB) is responsible, under the terms of the *Great Lakes Water Quality Agreement*, signed by Canada and the United States (the Parties), for "developing recommendations . . . pertinent to the identification, evaluation and resolution of current and anticipated problems related to Great Lakes water quality." As scientific advisor to both the International Joint Commission (IJC) and its Great Lakes Water Quality Board, the SAB formulates its advice by reviewing scientific information; examining analyses, assessments and recommendations; and consulting with relevant experts. Its breadth of responsibility encompasses all matters of a scientific or research nature relating to the operation and effectiveness of the *Great Lakes Water Quality Agreement*. Comprising 18 IJC-appointed members drawn equally from Canada and the United States, the SAB membership includes recognized experts in a variety of disciplines that include the physical, biological and social sciences. The SAB is organized into three work groups, 1. Ecosystem Health, 2. Parties Implementation, and 3. Emerging Issues; and is supported by a small IJC secretariat. The work of the SAB and its work groups is guided by a set of biennial priorities established by the IJC after extensive expert and public consultation. In addition to IJC priority topics, the SAB actively monitors a larger range of scientific issues relevant to *Great Lakes Water Quality Agreement* implementation and advises the IJC accordingly.

7.1.2 Priority Work of the Science Advisory Board as Assigned by the International Joint Commission

Priorities assigned to the SAB during the 2001-2003 biennium included the health effects of mercury in the Great Lakes basin (Chapter 1); the impacts of urban and urbanizing development on Great Lakes water quality (Chapter 3); and identification of "emerging issues" of interest under the terms and authorities of the *Great Lakes Water Quality Agreement* (Chapter 5). Individually and collectively, these priorities speak to the growing complexity of issues affecting the integrity of the waters of the Great Lakes basin ecosystem, the interrelatedness of the scientific, policy and management dimensions of such issues, and the need for science-based decision support processes that advance efforts to meet *Great Lakes Water Quality Agreement* objectives.

Full reports on the SAB's three priorities, including associated findings and recommendations, are found in other chapters in this report as indicated above. In developing these recommendations, a primary theme emerged concerning the SAB's advisory role under the terms of the *Great Lakes Water Quality Agreement*. Simply stated, the IJC and the Parties' ability to provide sound and effective leadership is fundamentally dependent upon the existence of a policy and institutional infrastructure that nurtures and provides for science-based decision support. **Toward that end, the SAB reiterates its recommendation for a thorough and expeditious review of the *Great Lakes Water Quality Agreement* with an eye toward revisions that safeguard past progress on water quality while acknowledging and addressing new priorities, ecosystem needs, scientific advances and institutional arrangements since its last revision some 16 years ago.**

7.1.3 Report on Watching Briefs

As a scientific adviser to the IJC and the Great Lakes Water Quality Board, the SAB is responsible for "developing recommendations on all matters related to research and the development of scientific knowledge pertinent to the identification, evaluation and resolution of current and anticipated problems related to Great Lakes water quality." In order to formulate its advice, the SAB is directed to review scientific information, to seek analyses, assessments and recommendations from other scientific groups and to report on all matters of a scientific or research nature relating to the operation and effectiveness of the *Great Lakes Water Quality Agreement.*

In order to fulfill this broad mandate, the work groups maintain watching briefs regarding new scientific knowledge and developments that may have implications for Great Lakes water quality. From time to time this information warrants a summary report from the workgroups to the SAB, whereupon it may be reviewed and approved for use in this report. The following reports on watching briefs do not include recommendations from the SAB, as they were not initiated directly as SAB sponsored activities. Where it is appropriate, "future directions" are indicated to suggest possible next steps. These reports on watching briefs thus provide an important opportunity for the SAB to alert the IJC and the Great Lakes Water Quality Board on a range of matters salient to the responsibilities under the *Great Lakes Water Quality Agreement*. The SAB's report on Annex 2 activities can be found in Chapter 2.

7.1.4 Acknowledgments

The capacity for the SAB to address IJC priorities and stay abreast of scientific advances is only possible through the dedication of its members, the commitment of many experts as friends of the IJC, and the active involvement of citizens and government officials, particularly on the occasion of public meetings and site visits of the SAB. The SAB acknowledges and thanks these many exceptional individuals for their support: Scott Abernathy, Rod Allan, Frank Anscombe, David Aspen, David Bellinger, Tonya Bender, Cherie Blair, Shelly Bonte-Gelok, Lee Botts, Larry Bourne, Ala Boyd, Stephen Brandt, Michael Brauer, Irene Brooks, James Brophy, Alexis Cain, John Carey, Doug Caruso, Laurie Chan, JaeEun Cho, Patricia Chow-Fraser, Murray Clammed, Mark Cohen, Donald Cole, Conrad De Barrios, Shelley Delaney, David Delaney, John Decliner, Joseph Depend, Chris Serosa, Miriam Diamond, Anabel Rojas Domínguez, Paul Drca, Arthur Dungan, John Eyles, Joel Fisher, Gary Foley, Glen Fox, John Gilkeson, John Gladki, Philippe Grandjean, Ken Greenberg, Gary Gulezian, Leah Hagreen, Doug Haines, Katie Harding, Lorrie Hayes, James Haynes, Diane Henshel, Matt Horvat, Abed Houssari, Susan Howard, Therese Hutchinson, Adele Iannantuono, Carol Izant, Togwell Jackson, John Jackson, Joseph Jacobson, Erik Janus, Margaret Keith, Kate Klenavic, Jeanine Klump, Joseph Koonce, Robert Krauel, George Kuper, John Kusnier, Charles Lalonde, Jack Lanigan, Patrick Lawrence, Leonard Levin, James Li, Lawrence Libby, Simon Llewellyn, Maureen Looby, Tony Lowery, Marc Lucotte, Don Mackay, Kathryn Mahaffey, John Marsden, Pamela Martin, Chris Marvin, Craig Mather, Ana Matu, Fred McEldowney, Donald McKay, James McKenzie, John Meier, Michael Meyer, John Mills, Kristin Mueller, Derek Muir, Michael Murray, Gary Myers, Melanie Neilson, Todd Nettesheim, Phu Van Nguyen, Jim Nicholas, Richard Norton, Eavan O'Connor, Gustavo Solórzano Ochoa, Ken Ogilvie, Al Olson, William Page, Scott Painter, Nigel Paneth, Chansy Paulik, Cynthia Pekarik, Alan Penn, William Rankin, Rob Reash, Andrew Rencz, Deborah Rice, R. Peter Richards, Lisa Richman, Elizabeth Robinson, Amy Roe, Ronald Rossmann, Margaret Round, Erin Rutherford, Tamara Saltman, Luz Helena Sanin, Dennis Schornack, Tom Schueler, John Sewell, Harvey Shear, Cole Shoemaker, Robert Slater, Mike Smalligan, Ted Smith, Paul Strohack, William Taylor, Joy Taylor-Morgan, Warren Teel, Jose Carlos Tenorio, Anna Tilman, Tao Tong, Luke Trip, David Ulrich, Michael Veschler, Peter Victor, Cristiena Vyver, Alan Waffle, John Walker, David Wallinga, Michael Weis, John Wellner, Richard Whitman, Peter Wise, Elizabeth Wright, Janice Yager and Kiauhong Xu.

For over three decades, PCBs and other persistent toxic substances have been a central concern under the *Great Lakes Water Quality Agreement*. As part of its responsibilities to inform the IJC of ongoing advances in this area of science, the Work Group on Ecosystem Health prepared the following update, particularly stimulated by recent publications in *Environmental Health Perspectives* that were noted by the SAB:

- Comparison of Polychlorinated Biphenyl Levels across Studies of Human Neurodevelopment (Longnecker *et al.* 2003);
- Increased Concentrations of Ploychlorinated Biphenyls, Hexachlorobenzene and Chlordanes in Mothers to Men with Testicular Cancer (Hardell *et al.* 2002);
- Effects of PCB Exposure on Neuropsychological Function in Children (Schantz *et al.* 2003); and
- A Longitudinal Examination of Factors Related to Changes in Serum Polychlorinated Biphenyl Levels (Tee *et al.* 2003).

7.2.1 Concerns Regarding Persistent Toxic Chemicals

Regulatory actions by the U.S. and Canada have led to significant reductions in PCBs and other toxic chemicals found in fish (U.S. EPA 2003a; 2003b). However, in recent years, the annual PCB decline has slowed considerably, and debate continues whether the PCB declines are continuing, following a first-order decay curve, or if a steady-state concentration is being approached. Firm conclusions are difficult to draw because of variability in the available data and a number of confounding factors such as changes in the foodweb dynamics caused by the introduction of invasive species.

The current levels of PCBs in fish still pose significant health risks to persons who consume moderate to high amounts of Great Lakes fish (Johnson *et al.* 1998; ATSDR 2000; Schantz *et al.* 2001). Children whose mothers consumed a few meals per month of Great Lakes fish have neurobehavioral and learning deficits associated with PCB exposure (Lonky *et al.* 1996; Jacobson and Jacobson, 1996; Darvill *et al.* 2000; Stewart *et al.* 2002). Other health concerns include effects on the endocrine and immune systems as well as increased risk of cancer (ATSDR 2000). Body burdens of PCBs and other persistent organic chemicals of Great Lakes fish consumers are from two to four times those of the general U.S. population (Anderson 1998; Hanrahan *et al.* 1999; Shantz *et al.* 1996, 1999). In order to achieve state and federal public health criteria, PCB levels in Great Lakes area waters and fish (open waters and certain tributaries) need to be decreased by one to three orders in magnitude.

In Lake Michigan, large lake trout greater than 26 inches long have PCBs 40 times state health advisory criteria, while coho salmon average about 10 times the advisory criteria

Extensive PCB based fish consumption advisories exist on each Great Lake and many connecting waters (U.S. EPA 2002a). Some fish advisories are due to dioxin (MDCH 2002). All Great Lakes state health departments use a criterion of 0.05 ppm PCB in fish fillets to establish fish advisories (U.S. EPA 2002). Fish may be consumed without restrictions below the 0.05 ppm PCB and, as levels rise above the criterion, persons are to restrict fish consumption from "one meal" of fish per week to "do not eat any meals" of fish (GLSFATF 1993).

In Lake Michigan, large lake trout greater than 26 inches long have PCBs 40 times state health advisory criteria, while coho salmon average about 10 times the advisory criteria (MDCH 2002, MDEQ 2003; WDH/WDNR 2002). The states of Michigan, Wisconsin, Illinois and Michigan advise all persons not to consume any meals of large lake trout (U.S. EPA 2002). Women of child bearing age and children under 15 are to limit consumption of coho salmon to one meal per month in Michigan, while the other states provide this advice to all persons (MDCH 2002; U.S. EPA 2002; WDH/WDNR 2002). Lake Michigan whitefish greater than 14 inches long north of Frankfort are not be consumed in any amount by anyone due to PCB and dioxin contamination (MDCH 2002).

In Lake Superior, considered the cleanest of the Great Lakes, ciscoes greater than 26 inches long are not to be eaten by anyone due to high levels of PCB and dioxin (MDCH 2002; Day 2003). Women and children are to consume no more than one meal per month of Lake

Superior chinook salmon over 22 inches long, which contain PCBs up to 20 times the state health criteria (MDCH 2002).

Open Great Lakes water monitoring also provides evidence of on-going contamination problems due to minute concentrations of persistent toxic substances. Concentrations of PCBs in the parts per quadrillion or picograms per litre (pg/l) give rise to concentrations in fish that exceed U.S. and state derived ambient water quality criteria to protect public health and wildlife (U.S. EPA 1996). As shown below, all open waters of the Great Lakes have PCB levels that are two to nine times the Great Lakes Initiative water quality value for PCBs, now revised to 26 pg/l to protect human health (U.S. EPA 1997b. A value of 120 pg/l has been derived for ecological protection (U.S. EPA 1996; 1997b). In 1997, monitoring cruises by the Lake Guardian revealed the following ambient concentrations of PCBs in the open waters of these respective lakes (U.S. EPA 2003a):
Lake Superior - 53 pg/l
Lake Michigan - 115 pg/l
Lake Huron - 62 pg/l
Lake Erie - 216 pg/l
Lake Ontario - 106 pg/l

7.2.2 Reducing Loadings of Persistent Toxic Chemicals

Both the U.S. and Canada are taking a variety of actions to reduce inputs of PCBs and other persistent toxic chemicals (Canada and U.S., 1997; U.S. EPA 2003b). Significant PCB sediment sources in Areas of Concern contribute to PCB levels in fish (U.S. PC 2002). For example, the Fox River, the largest known surface water source of PCBs to the Great Lakes, discharges from 125 to 220 kilograms of PCBs per year to Green Bay, with a portion of this loading being transported to Lake Michigan (WDNR/U.S. EPA 2002). PCB based fish consumption advisories for the river and bay have been in place since 1976 (WDNR/U.S. EPA 2002). Nevertheless, several thousand people consume fish from the river and bay (WDNR/U.S. EPA 2002).

PCB levels in the Fox Rivers and lower Green Bay are over a 1,000 times the GLI ambient water quality criteria to protect human health. PCB water column values in the DePere to Green Bay portion of the Fox River average

60,900 pg/l; in lower Green Bay, 17,800 pg/l; in upper Green Bay, 1,500 pg/l and are, respectively, about 2,340, 680 and 60 times the ambient water quality value in the Great Lakes Initiative to protect human health (WDNR/U.S. EPA, 2002). The PCB levels in water are more than 500 times the Great Lakes Initiative wildlife criteria in the Fox River, 150 times higher in lower Green Bay, and 12 times higher in upper Green Bay.

In order to achieve acceptable risks to persons and wildlife consuming fish, reduce fish consumption advisories, and reduce PCB loadings to Green Bay, U.S. EPA and the Wisconsin Department of Natural Resources plan to remediate over six million cubic yards of PCB contaminated sediments in the Fox River system, at a cost of approximately 400 million dollars (WDNR/U.S. EPA, 2002). Evaluations are also underway to evaluate remedial actions in the Kalamazoo River, which contribute from 39 to 50 kg/year to Lake Michigan and have PCB water column values comparable to those found in the Fox River (MDEQ 2002).

7.2.3 Policy Implications and Directions

To fully protect public health, continued and substantial efforts are required to reduce sources of PCBs and other persistent toxic chemicals which contaminate waters, fish, and wildlife of the Great Lakes basin. As stated in the 2002 U.S. Great Lakes Strategy (U.S. Policy Committee 2002): "The people of the Great Lakes region will know when we have been successful in our environmental protection efforts when the need to issue health advisories for fish consumption [has been] eliminated."

7.3 GREAT LAKES FISHERIES: RETROSPECTIVE AND CURRENT CONCERNS

Whether persistent toxic substances contributed to the extirpation of the fisheries resources in the Great Lakes basin has been a longstanding controversy within the Great Lakes scientific community. In the late 1980s, after the discovery of high levels of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCCD) in Lake Ontario fish and herring gulls, U.S. EPA sampled sediment cores from Lake Ontario to reconstruct a history of contamination. Subsequently, these data were used in a retrospective risk assessment for lake trout by Dr. Philip Cook, who reported his results to the Great Lakes Water Quality Board on July 15, 1993 in Chicago at its 102nd Meeting as part of the Water Quality Board's reevaluation of dioxins. Individual publications on the components of the retrospective risk assessment have been published in peer reviewed scientific literature. The synthesis was presented by Dr. Cook at the February 1999 Special Meeting of the Great Lakes Science Advisory Board to Assess Scientific Issues in Lakewide Management Plans for Critical Pollutants, and was included in the *1997 - 1999 Priorities and Progress under the Great Lakes Water Quality Agreement* report. Dr. Cook presented the completed retrospective risk assessment to the SAB's Work Group on Ecosystem Health on September 12, 2002 in Windsor, Ontario.

Historically, the Great Lakes had large stable lake trout populations until the last century and in each case, at some point in time, there was an extreme decline of the lake trout populations. In Lake Ontario, that decline started earlier than in the other Great Lakes, such that by 1960, lake trout were completely extirpated. There are a number of factors in the Great Lakes that certainly had major contributions to the decline of lake trout populations and the loss of reproducing populations. Predation by sea lamprey is one prime factor and commercial over-exploitation is another. There have been good programs since the 1970s for controlling the sea lamprey. These programs have been instrumental in re-establishing current day lake trout populations in Lake Superior and parts of Lake Huron. In conjunction with sea lamprey larvicide treatments of Lake Ontario tributaries, which began in 1971, attempts to reestablish lake trout populations through stocking of yearlings continued. Adult lake trout were present in the late 1970s, however, no sac fry from natural reproduction were observed until 1986.

In conjunction with sea lamprey larvicide treatments of Lake Ontario tributaries, which began in 1971, attempts to reestablish lake trout populations through stocking of yearlings continued. Adult lake trout were present in the late 1970s, however, no sac fry from natural reproduction were observed until 1986.

Dr. Cook and his colleagues graphically show that for at least a period of 40 years (1940 to1980) feral lake trout reproduction was compromised due to the presence of high levels of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) and TCDD-like contaminants in Lake Ontario (Cook *et al.* 2003). Of all the possible PCDD, PCDF, and PCB congeners, only 21 are known to be highly toxic to fish. These potent chemicals have chlorine substitution patterns that create molecular geometries with planar conformations similar to that of TCDD. Lake trout embryos and sac-fry are very sensitive to toxicity associated with maternal exposures to TCDD and the 20 structurally related chemicals. Over the last 15 years research has established the toxicity of the various congeners relative to TCDD and a set of toxicity equivalence factors (TEFs) based on trout early life-stage mortality has been developed. TCDD induced early life toxicity in lake trout resembles a non-infectious, edematous condition known as blue-sac and exhibits a very steep dose-response curve with a threshold beginning around 30 pg TCDD/g egg and ending with 100 percent mortality occurring near 100 pg TCDD/g egg.

Dr. Cook's retrospective risk assessment involved prediction of exposure and bioaccumulation of the TCDD-like congeners for years when egg samples were not available for analysis or when lake trout were absent from the ecosystem. Historical TCDD toxicity equivalence concentrations in lake trout eggs (TEC_{eggs}) were predicted from radionuclide dated sediment core sections. This assessment of exposures of lake trout embryos over time relative to recent conditions required: 1. fine resolution of radionuclide dating profiles in two sediment cores; 2. reference core specific biota-sediment accumulation factors (BSAFs) for each TCDD-like chemical in lake trout eggs; and 3. an adjustment of the BSAFs for the effect of temporal changes in the chemical distributions between water and sediments.

When compared to the dose-response relationship for overt early life-stage toxicity of TCDD to lake trout, the resulting TEC_{eggs} predict an extended period during which lake trout sac fry survival was negligible.

Beginning in 1940, following more than a decade of population decline attributable to reduced fry stocking and loss of adult lake trout to commercial fishing, Dr. Cook's model predicts increased sac fry mortality and possible sublethal consequences due to TCDD-mediated effects such that from1950, early life-stage toxicity alone explains the subsequent loss of the species. After 1980, reduced fry survival, associated with lethal and sub-lethal adverse effects, possibly complicated by other environmental factors, have probably contributed to a lack of reproductive success of stocked trout despite gradually declining TEC_{eggs}. Since 1995 there has been evidence of limited natural reproduction. Current day exposures to TCDD and TCDD-like chemicals are likely near the most probable no observable adverse effect concentration (NOAEL TEC_{egg} = 5 pg TCDD toxicity equivalence/g egg). However all the potential sub-lethal consequences to chronic low-level exposure to TCDD-like contaminants and other factors that may impact feral lake trout recruitment have not been fully elucidated. Dr. Cook concludes that other less sensitive fish species were probably also affected when the highest exposure levels were reached.

Assuming no new loadings of persistent bioaccumulative chemicals with TCDD-like toxicity, further reduction in TCDD-like toxicity risk will occur with declines in concentrations of PCDDs, PCDFs, and PCBs in the surficial sediments. Therefore, it seems most certain that not only did the persistent TCDD-like contaminants contribute to the historical extirpation of an economically valuable fishery resource in Lake Ontario, until very recently, these contaminants have also thwarted extensive restoration efforts. The work by Dr. Cook and his colleagues also shows that successfully curbing the inputs of persistent TCDD-like chemicals has improved conditions in Lake Ontario to the extent that overt early life-stage mortality due to TCDD-like chemicals is no longer viewed as a limiting factor for the restoration of self-sustaining lake trout populations.

Curbing the direct inputs of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) and TCDD-like contaminants into the Great Lakes has met with considerable success. Concentrations of PCBs and TCDD have declined in lake trout eggs to the extent that there is no longer concern that overt mortality contributes to loss of sac fry. However, this decline in the concentration of persistent contaminants has slowed considerably in recent years. There is a need to firmly establish the exposure conditions under which sublethal effects of TCDD and TCDD–like contaminants will no longer influence sac-fry and possibly contribute to subsequent recruitment problems.

Dr. Don Tillitt, Columbia Environmental Research Center of the U.S. Geological Survey, reported to the SAB's Work Group on Ecosystem Health, the findings of recently completed work on the sublethal consequences of TCDD contamination to rainbow trout sac fry. To investigate this, behavioral methods based on the optomotor response were performed to achieve preliminary evaluations of visual/motor function of viable swim-up trout developing from eggs exposed to graded doses of TCDD. Preliminary results indicate that significant deficits compared to the "normal" group in terms of detail discrimination (visual acuity), motion detection (flicker fusion thresholds) and prey capture occurred at one-third the lethal $consentration_{50}$. These effects also were associated with a reduction in the density of retinal ganglion cells. These results show that factors other than overt mortality may contribute to recruitment failures and imply that sac fry survivors of TCDD exposures above the no-observable-effects-level for overt egg mortality exhibit adverse effects that may impact subsequent survival and recruitment. The results also support the contention that current egg TCDD toxicity equivalence concentrations of 5 pg/g egg in lake trout from Lake Ontario are likely near the most probable no-observable-adverse-effect concentration and that the continued present day low-level of recruitment observed for feral lake trout must also be associated with other contributory factors.

Early mortality syndrome is the term used to describe an embryonic mortality affecting the offspring of all salmonids (coho salmon, chinook salmon, steelhead trout, brown trout and lake trout) in lakes Michigan and Ontario and to a lesser extent lakes Huron and Erie. Clinical symptoms of early mortality syndrome include loss of equilibrium, swimming in a spiral pattern, lethargy, hyper excitability, hemorrhage and death occurring between hatch and first feeding. Before 1993, mortality rates due to early mortality syndrome in Lake Michigan coho salmon offspring were around 20 percent. Beginning in 1993, early mortality syndrome mortality in coho salmon rose dramatically and, with the exception of 1997 and 1998, has proved to be problematic for both coho and chinook stocks for the last 10 years. The extent of early mortality syndrome in lake trout from lakes Ontario and Michigan has ranged from 5 to 70 percent averaging near 30 percent over the past 10 years. Low egg thiamine levels and enhanced survival following thiamine treatments are common characteristics of early mortality syndrome. In the past few years, there have been significant developments in early mortality syndrome research on Great Lakes species.

These developments include:

1. the demonstration that early mortality syndrome-like symptoms can be induced in the laboratory by a thiamine deficiency or by the application of thiamine antagonists;
2. the implication that inadequate egg thiamine may be associated with reduced fry recruitment even if the fish survived overt mortality;
3. the confirmation that the amount of thiamine degrading activity in the two exotic forage fish species (alewife and smelt) was up to one hundred times the activity observed in the native bloater species;
4. thiamine concentrations in forage fish is adequate to meet nutritional requirements but that thiamine degrading activity (thiaminase) can be highly variable within a species (temporal and geographic variability) as well as differing among the prey species that elaborate the enzyme; and
5. the isolation of two microbial strains of thiaminase positive bacteria from alewife viscera suggesting this as one possible source of thiaminase in these prey species.

Tillitt and coworkers conducted preliminary evaluations of visual/motor function of viable swim-up lake trout developing from eggs with very low thiamine concentrations (<1 nmol/g) and "normal" thiamine (> 10 nmol/g). Preliminary results indicate statistically significant deficits in the low thiamine group compared to the "normal" group in terms of detail discrimination (visual acuity) and motion detection (flicker fusion thresholds) evaluated both in photopic (day vision) and scotopic (night vision) conditions. This is consistent with other recent studies investigating predator avoidance or prey capture (Fitzsimons *et al*. 2002). Investigations on the effects of predator avoidance and zooplankton foraging showed significant but variable relationships, depending on egg source, between thiamine concentration and predator avoidance by fry. These studies set a tentative egg thiamine threshold of effect at 3 nmol/g. Together, these findings indicate that a majority of the lake trout and salmon populations are vulnerable to low thiamine and this may represent a major component in understanding the present day lack of recruitment of lake trout in the Great Lakes.

7.4 FISH AND WILDLIFE HEALTH EFFECTS AND EXPOSURE STUDY

7.4.1 Information

In 1998, Health Canada released data on the recent health of Canadians living in the 17 Canadian Areas of Concern relative to that of the province of Ontario as a whole. In 2001, Environment Canada initiated the ***Fish and Wildlife Health Effects and Exposure Study*** in Canadian Areas of Concern to determine if there are currently health effects in fish and wildlife that are associated with contaminants in the aquatic environment. There has been longstanding interest in understanding the origins and levels of toxic contaminants and their effects on animals in the Great Lakes by the SAB. While programs to monitor levels of persistent toxic chemicals are well established in the Great Lakes and show significant reductions in most traditionally measured chemicals, research on fish and wildlife health effects has been less extensive and no systematic monitoring of health effects occurs. Phase I (2001-2005) will investigate conditions in the Canadian Areas of Concern of the lower Great Lakes. Upon completion, the need for assessments at Areas of Concern in the upper Great Lakes will be determined. The objectives of the Environment Canada study are to:

1. Document health effects in fish and wildlife by measuring endpoints that are fundamental to the development, growth and reproduction of individuals and populations. A range of endpoints were chosen on the basis of sensitivity to chemical exposure, tangible results in previous studies, and economy of time and resources, to detect effects at the population, individual and subcellular levels.

2. Gather current environmental exposure data in water, fish and wildlife in Areas of Concern. In addition to measuring persistent organic pollutants, such as organochlorines, evaluate techniques in analytical chemistry to measure less persistent chemicals that may be present in fish and wildlife and determine environmental exposure.

3. Integrate and assess findings in lake-by-lake reports, making recommendations for long-term monitoring strategies, if required.

Health indicators chosen include:

- population trends over time across the Great Lakes basin;
- measures of reproductive health;
- status of the endocrine system including thyroid structure and function, and stress response hormones;
- diagnostic measures if organ function, including liver, kidney, pancreas, and bone; and
- tests for immune function.

Preliminary results of this study show that the health of wildlife in several of the Canadian Areas of Concern was affected in 2001. Results for the investigations of fish health are not yet available. Effects on reproduction, endocrine and immune function occurred in both birds and turtles, and were similar to some of the effects reported for human populations in some Canadian Areas of Concern. This work shows the value of, and need for, ongoing health effects monitoring in Areas of Concern and other contaminated areas in the Great Lakes basin, and in building a workable model.

7.4.2 Possible Future Directions

Given that Environment Canada's Fish and Wildlife Health Effects and Exposure Study has clearly shown that the health of herring gulls and/or snapping turtles is affected in several of the Canadian Areas of Concern, the SAB suggests that work employing a similar set of sensitive endpoints be undertaken on these species in other Areas of Concern and contaminated areas in the Great Lakes. In particular, in the United States Areas of Concern were persistent toxic substances are a problem, including Green Bay and Saginaw Bay.

7.5 THE AGENCY FOR TOXIC SUBSTANCES AND DISEASE REGISTRY'S (ATSDR) STUDY OF PUBLIC HEALTH IMPLICATIONS OF HAZARDOUS SUBSTANCES IN GREAT LAKES U.S. AREAS OF CONCERN

7.5.1 Information

The SAB has undertaken extensive work on commu nity health and has provided the IJC with advice on this issue over several biennial cycles. Through membership on the Work Group on Ecosystem Health, Dr. Christopher DeRosa of the Agency for Toxic Substances and Disease Registry (ATSDR) is extensively involved in IJC activities and has agreed to undertake further research at the request of the U.S. Section of the IJC, into the public health implications of hazardous substances in the Great Lakes U.S. Areas of Concern.

Great Lakes Areas of Concern are severely degraded geographic areas within the Great Lakes basin. They are defined by the *Great Lakes Water Quality Agreement* (Annex 2 of the 1987 Protocol) as "geographic areas that fail to meet the general or specific objectives of the Great Lakes Water Quality Agreement where such failure has caused or is likely to cause impairment of beneficial use of the area's ability to support aquatic life." The U.S. and Canadian governments have identified 43 such areas; 26 in U.S. waters, 17 in Canadian water (five of which are shared between U.S. and Canada on connecting river systems). All of these Areas of Concern are impacted by chemical contaminants from either local sources and/or remote sources of pollution. No organization has conducted a systematic evaluation of the contribution of hazardous waste sites to the environmental chemical contaminant burden and its impact on public health.

The IJC asked ATSDR to provide and evaluate information on public health assessments that it has conducted on hazardous waste sites within the 26 Areas of Concern. Specifically, the IJC asked if ATSDR could identify evaluated sites, the Hazard Category assigned to each site, relevant demographic information on the populations at risk, completed exposure pathways identified, and the priority substances following these pathways.

7.5.2 Possible Future Directions

The SAB, as the scientific advisory body to the IJC on matters related to water quality under the *Great Lakes Water Quality Agreement*, will be interested in reviewing the findings of ATSDR when they are made available to the IJC in July 2003.

7.6 WATERBORNE PATHOGENS IN THE GREAT LAKES: EXISTING AND EMERGING NEEDS FOR ASSESSING RISKS AND SOLUTIONS

7.6.1 Information

One of the key cornerstones of public health and community health is access to safe water and it has been known since the time of John Snow that exposure to polluted water leads to waterborne disease in the population (Vinten-Johansen *et al*. 2003). While cholera and typhoid were the diseases of concern in the 19th and 20th centuries worldwide, as we embark on the 21st century, developed nations are faced with new challenges, including new and reemerging bacteria, parasites and viruses. Part of the rationale for the Boundary Waters Treaty of 1909 was the occurrence of waterborne infectious diseases in the major cities throughout the Great Lakes and the possibility of pollution on one side of the boundary injuring public health on the other side.

The major concerns leading up to the negotiations and signing of 1972 *Great Lakes Water Quality Agreement* included considerations of diseases associated with microbiological agents. Much of the work of the 1978 *Great Lakes Water Quality Agreement*, amended by Protocol in 1987, has focused on persistent toxic substances, but the SAB is cognizant of its ongoing responsibilities to advise the IJC on the status of research on microbiological agents. At the 27th meeting of the Workgroup on Ecosystem Health, held in Windsor on November 13, 2002, Tom Edge of the National Water Research Institute in Burlington, Ontario, delivered a presentation on advances in research on ongoing issues in microbiology.

Waterborne disease outbreaks have risen in the U.S. in the recent statistics from the Centers for Disease Control, associated with drinking water and recreational waters (Lee *et al*. 2002). This is despite new rules and regulations governing water. Waterborne disease outbreaks also have been a growing concern in Canada (Edge *et al*. 2001), particularly after recent outbreaks in Walkerton, Ontario, and North Battleford, Saskatchewan. Currently there is no estimate on the amount of endemic waterborne disease in the Great Lakes region.

The U.S. Environmental Protection Agency is the federal agency charged with protecting and regulating our waters under the Safe Drinking Water Act of 1974 and the Clean Water Act, a 1977 amendment to the Federal Water Pollution Control Act of 1972. The two acts are often seen as disconnected and fail to address the hydrologic cycle from a holistic fashion. However, common approaches for examining protection of water basins and watersheds, use of science-based and risk-based data and developing information with a goal toward protection of ecological and human health, tie these two acts together. Microbial contaminants (waterborne pathogens) often have been ignored in water quality assessment and protection plans in lieu of a major focus on chemical contaminants. Yet, 60 percent of the water impairment for recreational use is based on excess bacterial fecal indicators and known health risks associated with exposure to waterborne pathogens have been described.

Health Canada is involved in a number of activities related to Canadian water quality, including the development of the Guidelines for Canadian Drinking Water Quality and the Guidelines for Recreational Water Quality. The Guidelines for Canadian Drinking Water Quality are produced in collaboration with the provinces and territories and other federal departments via the Committee on Environmental and Occupational Health. Health Canada is also working with the Committee on Environmental and Occupational Health to produce a 'Source to Tap' document that details a multi-barrier strategy for the provision of safe drinking water. This document describes best management practices designed to ensure drinking water quality, but can also be extended to recreational waters under the approach to source water protection.

Health Canada has identified a number of research gaps relating to pathogens of human health concern in the Great Lakes. Research is needed to improve our understanding of the sources of pathogens and their prevalence and distribution, in order to develop strategies for remediation.

Much attention has been given just recently to emerging pathogens. The reasons for this apparent "emergence" of pathogens has been attributed to many factors.

- Sensitive or susceptible populations: There is an increasing number of elderly and immunocompromised (transplant patients, AIDs patients) individuals in our communities, in addition to diabetics, infants, and pregnant women, all who may be more susceptible to severe outcomes (Gerba *et al*. 1996).

- Global transportation: The food supply comes from all over the world, thus leading to a distribution of pathogens (i.e. *Cyclospora*) and people are much more mobile and can transverse the globe in less than 24 hours, bringing infections with them.

- Antibiotic resistance: Due to the widespread application of antibiotics in medicine and in agriculture, antibiotic resistance is spreading. The World Health Organization has recently reported (WHO 2001) that increasingly drug-resistant infections throughout the world are threatening to make once-treatable diseases incurable (http://www.who.int/emc/amr.html).

- Zoonotic transmission: More animals and changes in agricultural practices may lead to greater chances for microbial transmission and spread from animals to humans.

- Evolution of pathogens: RNA viruses for example, during replication are lack repair mechanisms and can evolve quickly.

- Improved diagnostic tools: Diseases previously not recognized or microorganisms that are not culturable can now be studied through the use of powerful molecular tools.

The factors described above apply to the growing list of waterborne pathogens. In the Great Lakes there are a number of other factors associated with the risk of new pathogens and impacts on water quality and health. Table 1 gives an example of some of these.

The Great Lakes is home to some 30 million people and 80 percent of the shoreline is privately owned. Of the 31 Areas of Concern, 61 percent are impaired for swimming and 29 percent impaired for drinking water, respectively. The factors influencing the potential public health risks associated with water quality impairment and microbial contaminants are no doubt at play in this basin.

Waterborne pathogens can pose significant threats to aquatic ecosystems and diverse water supply needs for drinking, recreation, agriculture and aquaculture throughout the Great Lakes region. Instead of attempting to directly detect the presence of many possible pathogens in water, efforts to monitor the microbial quality of water have largely focused on detecting the presence of fecal indicator microorganisms such as total coliform bacteria or *Escherichia coli*. At present, the approach for making many microbial water quality decisions in the Great Lakes region is based upon use of fecal bacteria indicator tests; the ability to culture fecal bacteria in the laboratory; and the use of periodic water sampling regimes. While this can be a practical approach to a difficult challenge, it is increasingly recognized as being inadequate to ensure the safety of water supplies.

Existing microbiological indicators such as total coliforms have been shown at times to be poor indicators of fecal contamination. While the coliform *E. coli* is recognized as a better indicator of fecal pollution, its ecology in aquatic ecosystems is often different from other waterborne pathogens such as viruses and protozoa. The differences in persistence, means of transmission, or susceptibility to drinking water treatment lessen the value of coliforms as a predictor of the possible presence of diverse waterborne pathogens.

TABLE 1
Examples of Some Factors Influencing Water Quality and Health Risks

Factor	Outcome	Exposure issue	Health Issue
Population and Land-use Change	Increase in people and animals, more runoff.	More wastes discharges. More urbanization. CAFOs	Greatest access is to urban beaches. Sensitive populations at risk. (e.g. immuno-compromised, elderly, and young). Zoonotic pathogens.
Infrastructure	Aging wastewater and drinking water systems. combined sewer overflows, storm sewer overflows.	More untreated wastes entering waterways.	High loads of pathogenic bacteria, parasites and viruses
Transportation	Agents spread globally	Ballast waters bring in contaminants	Known ecosystem risks and cholera suspected in South America. Fecal coliforms found in ballast waters.
Climate	Increased storms and droughts	Impacts movement and survival of pathogens	Increased waterborne disease risks associated with rain, storms, and temperature.

7.6.1 Possible Future Directions

Direct Pathogen Monitoring and New Approaches

The SAB suggests that additional research is required to better understand the limitations of existing microbial water quality indicators, and to develop better pathogen-specific and new indicator detection methods. New methods should be used in surveys of key Areas of Concern where water quality impairment associated with indicators has been identified so that risk-based, science-based information can be used to assist in restoration efforts.

Table 2 describes some of the microorganisms that can be spread through contaminated water. In the last three decades, 1970 to 2000, numerous species of bacteria, parasites and viruses have been described that have caused important waterborne outbreaks throughout the world. Because most of the microorganisms that are waterborne are spread by the fecal-oral route, their occurrence and control in wastewaters, animal wastes, recreational waters and drinking waters are important. Key in the future to understanding and controlling emerging pathogens is the application of new tools for monitoring and studying these microorganisms (Huffman *et al*. 2003).

Many of these microorganisms are on the "Contaminant Candidate List" for the U.S. EPA and thus information on their occurrence in water is needed (LeChevallier *et al*. 1999a; 1999b). Many are transmitted both through drinking water and recreational water, including *E.coli, Cryptosporidium, Microsporidia*, and all the viruses. While with some of the others the transmission through the various water routes is uncertain (MAC and *Helicobacter*).

TABLE 2
Examples of "Emerging" Waterborne Pathogens of Concern Adapted from Quintero-Betancourt *et al*. 2003

Pathogen	First described as waterborne
***E.coli* 0157:H7** Associated with bloody diarrhea (hemorrhagic colitis) and Hemolytic uremic syndrome	1991
***Helicobacter pylori*,** Diarrhea, peptic and duodenal ulcer disease, gastric carcinoma	1991
Mycobacterium avium Complex Diarrhea and respiratory disease	1994
Cryptosporidium Profuse watery diarrhea (cholera-like), fluid loss, fever and abdominal pain	1984
Cyclospora Explosive, watery diarrhea, fatigue, anorexia, weight loss, nausea	1994
Microsporidia Gastrointestinal, pulmonary, nasal, ocular, muscular, cerebral, and systemic infections	1997
Toxoplasma (Flu-like symptoms). Painful swollen lymph glands in the cervical, supraclavicular, and inguinal regions. Fever, headache, muscle pain, anemia, lung complications. Fetus at greatest risk	1979
Coxsackievirus Aseptic meningitis, herpangina, paralysis, exanthema, hand, foot, and mouth disease, common cold, hepatitis, infantile diarrhea, acute hemorrhagic conjunctivitis	1990
Hepatitis viruses Fever, nausea, abdominal pain, anorexia and malaise, associated with mild diarrhea, arthralgias, scleral icterus. Cytologic damage, necrosis and inflammation of the liver (HAV)	1950
Norwalk-like viruses Diarrhea, vomiting, abdominal pain, cramping, low fever, headache, nausea, tiredness (malaise), and muscle pain (myalgia)	1968
Rotavirus Vomiting, abdominal distress, diarrhea, dehydration, fever	1983

Some of the most promising methods for direct pathogen detection include the application of antibody based methods. Immunomagnetic separation technologies have been used successfully to concentrate and purify very specific microorganisms. Antibody methods can also be used in combination with other methods such as with biosensors with liquid core wave guides that tend to enhance sensitivity.

Key microbes on the U.S EPA "Contaminant Candidate List" should and can be addressed. For example: Researchers have recently raised questions about the human health significance of the bacterial pathogen *Helicobacter pylori* in source waters used for drinking or recreation. While *Helicobacter pylori* is believed to be susceptible to existing methods of drinking water treatment, nonetheless, studies in rural areas of Pennsylvania have found this pathogen in well-waters that were determined to be coliform-free. Research is required to develop better methods to detect potentially emerging pathogens like *Helicobacter pylori* in aquatic ecosystems, and to better understand their ecology and the nature of the waterborne risk posed (Hegarty *et al.* 1999). We still know little about the ecology of this pathogen, including its occurrence in aquatic ecosystems, and its potential for waterborne transmission.

Viruses in coastal waters have been found to be potential sources of risk to recreators and are detected in 20 to 80 percent of the impacted sites (Griffin *et al*. 2002). Both cell culture methods and molecular techniques were used to address the pollution impact. Much of the contamination was suspected to be associated with storm flows and septic tanks. This review focused on marine coastal waters as very little work has been done in fresh water lakes and coastlines.

Cryptosporidium remains a concern in the Great Lakes water basin. It is the tenth anniversary of the largest waterborne outbreak ever recorded in the U.S. that occurred in Milwaukee, Wisconsin and was associated with contaminated water from Lake Michigan (MacKenzie *et al*. 1995). Associated with animal and human fecal wastes, new methods can now evaluate genotypes and infectivity giving a clearer picture of the sources and public health risks (Quintero-Betancourt *et al*. 2002).

Just as the Milwaukee outbreak had a tremendous impact on the reauthorization of the U.S. Safe Drinking Water Act, the Walkerton outbreak of *E.coli 0157H7* has promoted the development of a Canadian drinking water quality policy (Krewski *et al*. 2002). The dramatic impact on the community associated with both illnesses and deaths caused by the water supply has led to policies that will address basin/ aquifer protection and water quality monitoring and guidelines.

Advances in molecular biology are providing opportunities to develop innovative new microbial water quality monitoring techniques for the future. For example, applications of the polymerase chain reaction are increasingly being applied as tools to detect specific waterborne pathogens in aquatic ecosystems. Tremendous technological advances also are occurring in fields such as genomics and microfluidics. Genomics tools, such as DNA micro arrays, offer the potential to immobilize hundreds to thousands of DNA probes for different waterborne pathogens on a glass microscope slide. The micro array can then be applied to simultaneously screen a total DNA extract taken from microorganisms in a water sample for many potential pathogens. While there are challenges in applying such molecular techniques to environmental samples, there is a growing need to evaluate these new tools and seek ways to enhance existing culture-based approaches for monitoring microbial water quality. It will be important to explore potential applications of these molecular tools for studying the ecology of specific waterborne pathogens. For example, the whole genomes of *E. coli*, *Cryptosporidium, Giardia*, *Helicobacter pylori* and numerous viruses been sequenced, and genes can be immobilized onto a DNA micro array with the potential to enable comprehensive diagnostic or detection systems that can tell much about water quality and health risks. In addition, this lends itself to studies on gene expression, which may help to define key survival and transport modes.

New methods are being used in the Great Lakes. Investigators have recently published a recent paper looking at the presence of a potentially "new" indicator system using PCR for rapid specific assessment in Lake Michigan (Brinkman *et al*. 2003). Results were available in four hours and correlations of 0.93 r values were found when comparing the values to *Enterococci*, an indicator suggested by U.S. EPA for marine waters. More studies to address lower detection limits, relationship to the *E.coli* standard and public health risks should be supported. In addition, geographic transportability of such new methods and relationships will need to be investigated associated with nonpoint and point sources of pollution as well as storm events.

Ballast Waters

Estimates suggest that 21 billion gallons of ballast water enter into U.S. waters per year (Greenman *et al*. 1997). Ballast is defined as any solid or liquid that is brought on board a vessel to replace cargo, thereby stabilizing the ship's center of gravity. In most cases, coastal water is picked up as ballast in one area and carries with it a multitude of organisms that can then be disseminated globally and released as non-native and in many cases harmful species. Ballast waters originating from international ports and coastal waters have been the vector for the introduction of tens to hundreds of freshwater and marine species to the United States.

Non-indigenous species have been increasing despite regulatory programs, perhaps the most infamous of those with subsequent dramatic impacts on the ecosystem was the introduction of zebra mussels to the Great Lakes. These highly adaptive species with their rapid reproduction and ability to travel have caused tremendous problems for drinking water systems in taking water from the Great Lakes as well as endangering the food chain (Johnson and Padilla, 1996). It has been reported that over 80 days annually, the ports in the Great Lakes have at least one overseas vessel landing and over 64 have two and on 38 days annually three overseas vessels are landed (Niimi 2000).

The Non-indigenous Aquatic Nuisance Prevention and Control Act (1990) as well as the National Invasive Species Act (1996) have given the Coast Guard the authority to regulate ballast water management practices to prevent the discharge of ship borne ballast water in U.S. waters of the Great Lakes.

Currently management practices fall into two general categories:

- open ocean ballast water exchange; and
- ballast water treatment systems.

In 1993, a mandatory off shore water exchange was implemented for all overseas vessels entering the Great Lakes. However, the efficacy of this process for preventing introduction of invasive species has been questioned. Therefore, treatment of the ballast water has been examined for both on land and on board systems (Greenman *et al*. 1997).

Safe discharge has been broadly defined as the removal of fish (larvae), invertebrates, seaweed, algae, fungi, protozoa, bacteria and viruses. A variety of approaches have been suggested in determining what is considered "safe." Current densities of organisms are estimated at 170 metric tonnes and levels through exchange can decrease these to 2 metric tonnes. Several other types of goals have also been proposed:

- Zero discharge of phytoplankton and zooplankton, maximum concentrations of *E. coli* of 35 colony forming units and Enterococci of 126 colony forming units.
- Drinking water goals that include 99.99 percent reduction of viruses and 99.9 percent reduction of protozoa with no detectable total coliforms per 100ml.
- Kill rate of 95 percent of six representative target species (vertebrates, invertebrates, phytoplankton and macroalgae).

It has been reported that over 80 days annually, the ports in the Great Lakes have at least one overseas vessel landing and over 64 have two and on 38 days annually three overseas vessels are landed (Niimi 2000).

These goals require monitoring and establishment of discharge criteria and/or demonstration of treatment efficacy to achieve specific reductions (removal or inactivation).

Source Tracking

The SAB suggests that a major effort in the Great Lakes basin should focus on assessment of the source tracking methodologies and building databases, baseline information for library based methods and verification studies.

While fecal indicator tests, such as for coliforms, currently provide the basis for many boil water advisories and beach closures, new tools are being developed to determine the sources of fecal pollution for quickly taking appropriate corrective actions. There are a variety of techniques under active investigation that could assist in determining the origin and transboundary fate of fecal pollution in the Great Lakes region. One promising area of research for addressing waterborne pathogen concerns and nonpoint sources of pollution in the Great Lakes is microbial source tracking to determine the origins of fecal pollution (Scott *et al*. 2002; Simpson *et al*. 2002). This includes, ribotyping, antibiotic resistant profiling, coliphage typing, box-PCR, *E.coli* and *Enterococci* gene specificity markers, enteric viruses typing, and *Cryptosporidium* genotyping. Some of these include methods that require an extensive library be built while other methods have greater host specificity. Any of these methods need to be evaluated and verified in survey work which builds base line data.

Environment Canada's National Water Research Institute, Burlington, Ontario is exploring box-PCR DNA fingerprinting and antibiotic resistance profiling techniques to characterize *E. coli* isolates from nearshore waters of Lake Ontario. It is possible to first build a library of such fingerprints or profiles of *E. coli* isolates obtained from local fecal sources such as human feces, livestock manure or Canada geese feces. Then the fingerprints or profiles of *E. coli* isolates obtained from water samples are matched with those from the library to help determine the source(s) of fecal pollution. There are a number of researchers in Canada and the United States that are actively exploring applications of different microbial source tracking techniques in the Great Lakes region. This is an area of research that will undoubtedly be growing in the future and providing new tools to more quickly and accurately determine the sources of fecal pollution responsible for contaminating drinking and recreational waters in the Great Lakes.

Sewage Treatment and Urbanization

The SAB suggests that loading of microbial pathogens into rivers and into the lakes from sewage discharges, including viruses and parasites should be estimated in order to examine the carrying capacity of the waterways and risks.

Most conventional wastewater treatment facilities, while addressing suspended solids, biological oxygen demand and in some cases fecal coliform bacteria, provide minimal reductions of enteric pathogenic viruses and protozoa. Levels between 10 to 100 parasites and viruses per 100 liters can be detected in most secondary effluents (Rose *et al.* 2001a) and it can be estimated that as much as one million pathogenic organisms per day can be loaded to a water body from a single facility. Greater risk and greater concentrations are seen due to combined sewer overflows and storm sewer overflows flows, however the data supporting the risk is often not collected.

Little is known in regard to the fate (survival and transport) of these types of enteric pathogens in the Great Lakes. Information is needed so that these data can be used in models to address the potential for public exposure on beaches and through drinking water systems.

Climate Change

The SAB suggests that water quality trends in key waterways should be explored under various flow scenarios. Storm events and water quality changes need to be investigated in areas where public exposure and health risk may occur.

The recent report on "Confronting Climate Change in the Great Lakes Region: Impacts on our Communities and Ecosystems" (Kling and Wuebbles, 2003) has been released and has some startling findings in regard to impact on water quantity. The suggested changes in water quantity will influence the quality of the water as well, but these have not been quantified, yet it is clear that these changes could influence the risk of waterborne disease (Patz *et al.* 2000; Rose *et al.* 2001b). Some of the predictions include: increases in temperatures by the end of the century could further the trend of lowering lake levels, and could lead to more/longer flood and drought cycles; inland lakes and headwaters in rivers will have lower levels particularly in the summer; and soil moisture will decrease. This will mean more competition for water resources and will change the overall pollution level (less dilution), increase short-term impacts (more storms) and decrease the carrying capacity to handle the microbial contamination.

For microbial contamination even these short-term trends are of concern as illness can take place with even short-term/transient contamination events. In addition, much of the stress will be more obvious in the summer when more people will be in, around and near the waterways and use of the lakes for recreation is high.

Modeling

The SAB suggests that recent hydrodynamic models that are being investigated for ecosystem predictions should be examined and ground-truthed for microbial indicator pollution transport.

Great Lakes scientists are using multiple regression techniques to develop more sophisticated models for predicting beach water quality in Chicago and Milwaukee based on indicator concepts for identification of risk. These models include rainfall during the previous 24 hours, wind, solar radiation, water temperature, lake stage, water turbidity and pH. Rainfall, wind and turbidity are indicative of the strong influence that storms have on *E. coli* concentrations. At the Milwaukee beach, storm effects result primarily from sewage overflows into tributary rivers that get pushed shoreward by easterly winds. The Chicago beach is not directly influenced by stream inflows, but storms stir up *E. coli* laden sand in the breaker zone. Solar radiation is a negative term in the model that reflects UV-mediated bacterial die-off during bright sunshine. Water temperature and lake stage represent conditions that lead to high bacterial concentrations during non-storm periods. Bacterial populations grow faster in warm water and bacteria become more concentrated when lake level falls at the beach in Chicago. These models were evaluated by comparing predictions of *E. coli* concentration exceeding U.S. EPA's recommended threshold of 235 colony forming units (cfu)/100mL with measured concentrations. The model correctly predicted 66 of 90 events at the Milwaukee beach and 50 of 57 events at the Chicago beach. Model errors were evenly split between false negatives and false positives for the Milwaukee beach, but five of the six incorrect predictions for Chicago are ones that would have led to overprotective actions.

This type of research investigation should be expanded to other watersheds and improved so that it can address risks associated with pathogenic microorganisms. This will aid in developing a predictive approach for the detection of risk.

7.7 ACTIVITIES AND MEETINGS OF THE SCIENCE ADVISORY BOARD FOR THE 2001-2003 BIENNIAL CYCLE

123 November 29, 2001
Windsor, Ontario
Special Presenters:
- Great Lakes Environmental Indicators Project
  Dr. Deborah Swackhamer, University of Minnesota
- Consortium for Oceanographic Research and Education
  Dr. Anders Andren, University of Wisconsin-Madison

124 February 28, 2002 Michigan League,
Ann Arbor, Michigan
Joint WQB/SAB status assessment group session to develop a comprehensive, systematic program evaluation approach to assessing progress in Areas of Concern
Special Presenters:
- Modeling the Atmospheric Deposition of Mercury to the Great Lakes, Dr. Mark Cohen, NOAA
- Why Don't They Listen? The Challenge of Conveying Technical Knowledge to Local Officials And Getting Them to Act on It.
  Dr. Richard Norton, University of Michigan

125 May 1-2, 2002
Wyndham Hotel, Toledo, Ohio.
Tour and Public Meeting on Scientific Issues on the Maumee Area of Concern
Special Presenters:
- Trends in Water Quality in the Lake Erie Agricultural Systems for Environmental Quality Rivers and Streams 1975-1995.
  Dr. R. (Pete) Richards, Heidelberg College
- What is the Maumee RAP? Matt Horvat, Toledo Metropolitan Area Council of Governments and Cherie Blair, Ohio EPA

126 September 13, 2002
Windsor, Ontario
Special Presenters:
- Great Lakes Beach Closures: Problems and Prospects. Dr. Richard Whitman, USGS
- Random Thoughts on Aquatic Science and the Great Lakes.
  Dr. Jan Ciboroski, University of Windsor

127 November 14, 2002
Windsor, Ontario
Special Presenters:
- A Scientific Primer on Great Lakes Mercury Issues.
  Dr. Milton Clark, U.S. EPA
- The Grosse Pointe Environmental Health Profile.
  Dr. Brian McKenna, LocalMotion

January 7, 2003
Metro Hall, Toronto, Ontario
Workshop on Impacts on Urban Land-use Impact on Great Lakes Water Quality

February 5-7, 2003
Wingspread, Racine, Wisconsin
Expert Consultation Meeting on Emerging Issues

February 26-27, 2003
Windsor, Ontario
Workshop on an Ecosystem Approach to the Health Effects of Mercury in the Great Lakes

128 April 8, 2003
Washington, D.C.

129 May 7-8, 2003
Windsor, Ontario

130 September 18, 2003
University of Michigan, Ann Arbor, Michigan

7.8 SCIENCE ADVISORY BOARD AND WORKGROUP MEMBERSHIP 2001-2003

Dr. Anders Andren (to December 2002)①④
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Sea Grant Institute
Madison, Wisconsin

Dr. William Bowerman①②
Clemson University
Department of Forestry and Natural Resources
Pendleton, South Carolina

Dr. John Braden①④
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University of Illinois at Urbana-Champaign
Urbana, Illinois

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National Water Research Institute
Burlington, Ontario

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Environmental Health and Toxicology
University at Albany
Rensselaer, New York

Dr. J.Milton Clark①②
U.S. Environmental Protection Agency
Chicago, Illinois

Ms. Maxine Cole①②
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Dr. Donald Dewees①③
Department of Economics
University of Toronto
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Dr. Michael Donahue *(U.S. Cochair)*①③
Great Lakes Commission
Ann Arbor, Michigan

Mr. Glen Fox①②
Canadian Wildlife Service
Ottawa, Ontario

Dr. Isobel Heathcote *(Canadian Cochair)*①④
University of Guelph
Guelph, Ontario

Dr. Keri Hornbuckle (to Sept. 2002)①④
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① Science Advisory Board
② Workgroup on Ecosystem Health
③ Workgroup on Emerging Issues
④ Workgroup on Parties Implementation

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Mr. Peter Boyer①③
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Dr. Christopher DeRosa②
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Dr. Brian Gibson②
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Mr. Michael Gilbertson②
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Ms. Ann MacKenzie①
International Joint Commission
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Ms. Victoria Pebbles
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Ann Arbor, Michigan

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① Science Advisory Board
② Workgroup on Ecosystem Health
③ Workgroup on Emerging Issues
④ Workgroup on Parties Implementation

7.9 REFERENCES

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COUNCIL OF GREAT LAKES RESEARCH MANAGERS

CHAPTER EIGHT Council of Great Lakes Research Managers

Contents

8.1 INTRODUCTION

The Council of Great Lakes Research Managers (Council) was created by the International Joint Commission (IJC) to serve as a principal advisor on research programs and needs. Originating in 1984 as part of the Science Advisory Board, the Council was placed directly under the IJC in 1991. The Council's purpose is to enhance the ability of the IJC to provide effective leadership, guidance, support and evaluation of Great Lakes research as it applies to the provisions of the Great Lakes Water Quality Agreement. The Council's responsibilities include:

- promoting effective communication and collaboration between researchers and agencies in Canada and the United States;
- encouraging researchers to share their findings;
- compiling a summary of current and planned research programs related to the *Great Lakes Water Quality Agreement*, particularly those called for by Annex 17 - Research and Development;
- identifying and prioritizing research needs to identify gaps and encourage the U.S. and Canadian governments, the Parties to the Agreement, to shift funding toward studies directly relevant to the Agreement's purpose; and
- reviewing the impact of research recommendations made by itself, the Great Lakes Science Advisory Board, the Great Lakes Water Quality Board and the IJC.

Membership consists of individuals managing federal, state and provincial research programs in the United States and Canada, and also includes representatives from academic institutions and private industry. Binational members representing the Great Lakes Fishery Commission and the International Association for Great Lakes Research also participate. All members serve in a personal and professional capacity at the pleasure of the IJC, usually for terms of three years.

The keyword for the Council's activities during the 2001–2003 priority cycle was teamwork. Recognizing that advisory board/council activities often overlap and the great value of multi-board collaboration, the Council focused on working in partnership with the Great Lakes Science Advisory Board, Great Lakes Water Quality Board and International Air Quality Advisory Board to address priority issues. The Council also continued its efforts to improve science vessel coordination and to institute improvements to the Great Lakes – St. Lawrence Research Inventory. In addition, the Council scoped out research needs associated with microbial pollution and unmonitored chemicals to expand on past IJC work related to this aspect of the human health and has included its findings and recommendations in section 8.2.

Council members participated in the following multi-board work groups to address priorities for the 2001 -- 2003 priority cycle: the Great Lakes Science Advisory Board work group for the Great Lakes emerging issues workshop (Chapter 5) and its work group on urban land use the Great Lakes (Chapter 3); the Great Lakes Water Quality Board climate change priority subcommittee (Chapter 4); and the Annex 2 Task Group (Chapter 2). These work groups organized workshops to address IJC priority issues and served to identify new or redirected research and data collection efforts required in the Great Lakes. Council members also attended the workshops and provided input to the proceedings, findings and resulting research recommendations.

The Council of Great Lakes Research Managers would like to acknowledge the efforts of all of those who, although they were not official members of the Council, made a significant contribution to the report. They include: Cheryl Martin, Will Robertson, Sheridan Haack, Doug Alley, John Gannon and Giovanna Stasiuk.

8.2 UNDERSTANDING MICROBIAL POLLUTION AND UNMONITORED CHEMICAL CONTAMINANTS IN THE GREAT LAKES BASIN

8.2.1 Activities

The Council focussed on the issue of microbial pollution and unmonitored chemicals during the 2001-2003 biennial reporting cycle. The threats of unmonitored chemicals and pathogens in waters used for human consumption or recreation are very similar and may be linked. For example, it is thought that the unmonitored release of antibiotics into the environment is part of the supposed cause of resistant bacteria. This report expands upon the Council's advice regarding emerging contaminants and pharmaceuticals in Great Lakes waters published in the 1999-2001 Priorities Report. Those recommendations were reflected in concerns expressed by the IJC in its discussion of unmonitored chemicals in Section 13 of its *Eleventh Biennial Report on Great Lakes Water Quality* and have initiated a dialog with government representatives to address these important human health concerns. In addition to concerns regarding unmonitored chemicals, the *Eleventh Biennial Report* highlighted the risk of alien invasive species and microorganisms into Great Lakes waters through ballast water discharge. These prior IJC reports led the Council to explore research needs associated with microbial pollution and to provide further input on this critical human health issue in the 2001-2003 Priorities Report.

8.2.2 Purpose

The Council's activities in this area are aimed at addressing human health issues related to water quality that are not well understood and are not being addressed by the parties to the *Great Lakes Water Quality Agreement* or other regulatory agencies. These issues fall into two major categories:

- The impacts of non-regulated chemicals, such as pharmaceuticals, similar compounds used in agriculture, personal care/household products, etc.
- The introduction of microbial pathogens, such as toxic algae or bacteria, viruses, and protozoa of human health concern.

The Council summarizes relevant issues concerning the impact of non-regulated chemicals and the introduction of microbiological agents, and it highlights research needs or gaps relating to these threats to human health in the Great Lakes. It is important to note, in the context of this discussion, that pathogens may be introduced from outside sources, existing pathogens that are not being monitored well enough, or "newly emerging" pathogens that have evolved in the environment. The Council's recommendations for addressing this problem hold true regardless of the point of origin.

8.2.3 Background

In recent years, many prescription and non-prescription drugs and household products have been found in wastewater treatment plant effluents, surface waters and ground water throughout the United States (Todd and Haack 2001). Many of these chemicals are bioactive (the intended purpose of pharmaceuticals) and they include a wide variety of industrial and agricultural chemicals known to mimic or inhibit various endocrine functions, such as effects on development, reproductive function, neurobehavior or the immune system (NRC 1999). Unlike the priority persistent toxic pollutants identified in the Great Lakes Water Quality Agreement, most of these chemicals, potentially capable of altering biological functions of exposed individuals and populations, are unregulated and, thus, unmonitored.

There is a similar lack of regulation and monitoring for pathogens because for the most part only fecal indicator bacteria are required to be regulated in drinking water. The presence of these bacteria only indicates whether or not fecal pollution has occurred, but not necessarily whether pathogens are present. Indeed, some organisms of concern, such as toxic algae and cyanobacteria, are present in the absence of fecal pollution. The American Society for Microbiology reports "an alarming lack of focus on microorganisms" in studies of the nation's watersheds and recommends "scientific assessment to address the microbial safety of the nation's waters (Rose *et al.* 1999)." The Centers for Disease Control report that more than one third of waterborne disease outbreaks in U.S. recreational and drinking water from 1971-1998 were due to "acute gastrointestinal illness of unknown etiology (CDC 2000)." A similar situation exists in Canada.

The Great Lakes are subjected to environmental stresses similar to those experienced by other large bodies of water

It is clear that public health agencies in the Great Lakes region and elsewhere must do more to identify and quantify the potential threats of unregulated chemicals and pathogens in waters used for human consumption or recreation.

impacted by urban development, agriculture and other industries. Several activities impact on the prevalence, types and persistence of pathogens in the Great Lakes, including commercial activities such as foreign shipping, agriculture and food processing, increased urban development leading to storm water runoff, extreme weather events related to climate change, and increased recreational swimming and boating. Some of these activities may lead to the introduction of "new" pathogens possessing unique genetic attributes, possibly including resistance to a variety of antibiotics.

Despite improved public sanitation and water treatment in the past century, the risk of health effects associated with exposure to pathogens and chemicals in the Great Lakes may be increasing. The combination of three forces may cause humans to be more vulnerable to microbial pollution.

- Increased risk of exposure to new pathogens resulting from increasing international commerce (e.g., ballast water, food, immigration).

- Evolution of microbial resistance to antibiotics due to their widespread use.

- Greater prevalence of individuals with impaired immune systems due to HIV, Lupus, the use of immunosuppressive drugs in organ transplant recipients, etc.

It is clear that public health agencies in the Great Lakes region and elsewhere must do more to identify and quantify the potential threats of unregulated chemicals and pathogens in waters used for human consumption or recreation.

8.2.4 Recommendations: Research Needs Associated with Pathogens

There is insufficient information on the environmental occurrence, distribution, transport, persistence or ecology of pathogens in the Great Lakes. Monitoring methods that rely on bacterial indicators of fecal pollution provide little or no information on the presence of pathogens, such as viruses, protozoa or non-fecal bacteria, that may be present in Great Lakes' waters and which could affect human health. Although some work is being done at specific sites in the U.S., very little information exists regarding the prevalence, distribution, sources and persistence of pathogens in the Great Lakes as a whole, highlighting the need for increased research.

The Council recommends the following to the IJC:

- **Recommend to the Parties that the following types of research/surveillance be conducted:**
  - **Determine the prevalence of selected enteric microbial pathogens, and microbial toxins, such as cyanobacterial toxins, in the Great Lakes.**
  - **Identify sources of microbial pathogens to waters used for human consumption or recreation, such as from ships' ballast; wastewater treatment plant effluent, storm water and agricultural feedlot runoff; boating wastes—gray and black water; and septic systems.**
  - **Develop testing methods and procedures for information exchange to facilitate identification of pathogens in environmental samples and enable that data to be compared with reports of disease outbreaks.**
  - **Study the environmental ecology of pathogens in aquatic systems to find ways to disrupt their distribution and life cycles before they can cause disease in humans.**
  - **Determine the significance of recreational and occupational water exposure to/in the development of gastrointestinal illness and identify risk factors.**
  - **Develop strategies and priorities for remediation, such as the appropriate discharge of ballast water or black and gray waters, based on identified risk factors.**
  - **Determine the prevalence and persistence of these pathogens before and after extreme weather events, and as a result of long-term climate change, such as lower lake levels or higher temperatures.**

8.2.5 Recommendations: Research Needs Associated with Unmonitored Chemical Contaminants

To further understanding of the extent of the problem of bioactive chemicals in Great Lakes' waters will require action in three major areas:

- greater attention must be focused on the problem such that an accurate assessment of the current status of these substances can be developed,
- a better understanding must be obtained of the fate of these substances in soil and sediment and in aquatic systems, and
- once the levels of these substances are understood, evaluate their pharmacologic and toxicologic activities to permit some estimation of the risks of exposure.

The Council recommends the following to the IJC:

- **Recommend to the Parties that the following types of research/surveillance be conducted:**
  - **Examine the output of these chemicals from wastewater and drinking water treatment plants.**
  - **Summarize the actual levels of these constituents detected in water supplies and compare these values to their reference or effect levels; or determine their effect levels, if unknown.**
  - **Determine if there are biotic indicators of the effects or presence of these chemicals.**
  - **Conduct experimental analyses of degradation times for these chemicals under natural conditions.**
  - **Determine if wastewater or drinking water treatment processes can be changed to reduce or remove these chemicals.**

In summary, the problems with pathogens and emerging chemical contaminants are the same in practical terms — they are present in the environment, they are not regulated and they could present a health risk. There has been some ground breaking work done recently in the study of concentrations of pharmaceuticals and other organic contaminants in both the U.S. and Canada. These studies include the United States Geological Survey Toxic Substances Hydrology Program National Reconnaissance study of pharmaceuticals, hormones and organic wastewater

contaminants in 139 streams across 30 states (USGS 2000); Centers for Disease Control and Prevention studies of antimicrobial resistance; and the Canadian Toxic Substances Research Initiative to evaluate the occurrence and concentrations of prescription and non-prescription drugs in the effluent of Canadian sewage treatment facilities (Metcalf *et al.* 2002). The National Oceanic and Atmospheric Administration's Great Lakes Environmental Research Lab currently has ballast water research projects underway that include analysis of ballast water samples for pathogens. The Canadian National Water Research Institute, in collaboration with academic institutions, is currently studying the application of microbial source tracking techniques (antimicrobial resistance and rep-PCR) to determine sources of fecal contamination and pathogen pollution in the Great Lakes, is conducting a research study of sewage treatment effluents, groundwater sources and drinking water treatment facilities to determine levels of pharmaceutical concentrations. Such efforts must be recognized, funded and fully supported.

Research documenting the presence and concentrations of pathogens, pharmaceuticals and unregulated chemical contaminants is just a first step in assessing the risk to human health. Much more needs to be done in order to provide policy makers with the knowledge required to decide whether harmful quantities of pathogens and unregulated chemical contaminants are present and the appropriate response. Additional research must be conducted in order to learn about the occurrence of pathogens and emerging chemical contaminants, their fate and transport in the environment, the risk to humans, and whether that risk can be mitigated by wastewater or drinking water treatment.

8.3 GREAT LAKES - ST. LAWRENCE RESEARCH INVENTORY

8.3.1 Background

The Great Lakes - St. Lawrence Research Inventory is an Internet-based, searchable database that collects and disseminates information on research programs relevant to the **Great Lakes Water Quality Agreement**. It enables managers to examine the impact of research, the interrelationships between research disciplines, the adequacy of research related to government agreements and to link research to policy questions. It also allows Great Lakes researchers and policy makers to identify similar studies, network and share experiences. This allows users to increase efficiency and benefit from current research or experience gained from outside traditional networks.

The objectives of the research inventory are to:

- provide an effective tool for both professionals and the public to learn about contemporary research projects related to the Great Lakes ecosystem
- help locate researchers working on projects related to the Great Lakes region.
- provide managers with key data concerning resources dedicated to research in the Great Lakes - St. Lawrence region.
- provide a central source through which people can access both traditional and nontraditional sources of information about the Great Lakes ecosystem.
- reduce the delay between the production of information and its dissemination to a wide audience.
- facilitate communication between professionals working in related fields, enhance coordination and reduce duplication of effort.

8.3.2 Redesign and Development

During the past two years the Research Inventory has dramatically improved. Previous versions of the database relied on fax, mail or e-mail submissions of research project data forms, which were then manually entered into the database by the IJC's Great Lakes Regional Office. Each inventory, whether on paper or computer database versions, represented a "recount" of all projects that could be identified in the region. Short term, rapidly changing projects and ongoing, long term projects that had not changed in years were counted each year. This system was highly inefficient and as soon as an inventory was released, it was out of date since the process could not keep pace with change. Earlier attempts to automate the database and to take advantage of the power of the internet did not allow users to directly interface with the database and were not capable of the types of searches that most internet users commonly find on the web today.

Participation with the Research Inventory has for the most part always been voluntary; however some granting organizations have begun to require participation with the Research Inventory as a condition of the grant. This tie to funding provides a strong incentive to participate and is seen as a very positive step forward. The Council also recognizes that researcher's time is at a high premium, that most organizations have in-house databases that require periodic data input and that researchers would appreciate only being required to enter project data once.

All of these problems were addressed during the 2001 – 2003 priority cycle by totally redesigning the inventory as a web-based, interactive database. A survey of users was conducted to identify needs, comments submitted in response to previous inventories were considered and Council members volunteered to conduct prototype testing. Processes were programmed into the new system to provide secure access to project data, ensure data integrity and to reduce duplication of efforts. The new database was activated in June 2002 and since that time has been further improved through the addition of refined search features and a help function added in March of 2003.

Today's version of the Research Inventory allows projects to be continuously entered, updated, searched and sorted directly from the Internet, and is fully capable of providing up-to-date information on research projects relevant to the Great Lakes region. Maintenance and down time have also been greatly reduced.

8.3.3 Participation

Now that improvements to the inventory are in place, the challenge is to attract a high level of participation from research organizations throughout the basin. Researchers entering data on a typical new project will find that it usually takes no more than approximately 10 to 20 minutes and that existing projects can be updated in less than five minutes. There are currently 570 projects entered in the inventory. Efforts by the Council to compare data entered in the inventory with that identified on agency web sites indicates that this may represent only about half of the projects currently underway. Consequently, the distribution of projects in the inventory at this time can only be regarded as an indicator of activity and not a precise measure. In order to be a true "inventory" and reach its full potential, the Council must press for full participation. Discussions with managers and researchers indicate that most recognize the importance of a research inventory for the effective management of resources, however three obstacles have been identified that must be overcome in order to improve participation.

- the voluntary nature of the inventory;
- the lack of incentives; and
- resource limitations.

To overcome these obstacles the Council intends to actively promote the inventory and increase awareness about its value as a tool to effectively compete for and manage research funds. The Research Inventory can reveal gaps in current research and lend strong support for research proposals designed to fill those gaps. Participation with the Research Inventory has for the most part always been voluntary; however some granting organizations have begun to require participation with the Research Inventory as a condition of the grant. This tie to funding provides a strong incentive to participate and is seen as a very positive step forward. The Council also recognizes that researcher's time is at a high premium, that most organizations have in-house databases that require periodic data input and that researchers would appreciate only being required to enter project data once. Accordingly, the Council is working in cooperation with Canada's National Water Research Institute, the Great Lakes Commission and other organizations to identify ways to share data and link databases in order to reduce the need for duplicate entries.

8.3.4 Recommendation

The Council recommends the following to the IJC:

- **Recommend to the Parties that organizations granting funds for Great Lakes research be encouraged to routinely utilize the Great Lakes – St. Lawrence Research Inventory as a tool to identify gaps in current Great Lakes research and that researchers/managers be provided with incentives to participate.**

For more information regarding the Great Lakes – St. Lawrence Research Inventory, please visit our web site by selecting the link on www.ijc.org.

8.4 SCIENCE VESSEL COORDINATION

8.4.1 Background

Great Lakes science vessels are vessels used for research, training and outreach by both public and private institutions. They are a critical part of U.S. and Canadian science programs geared to monitor and protect the quality of the Great Lakes ecosystem. Science vessels support a wide range of research and monitoring activities related to the physical, chemical and biological integrity of the largest freshwater system in the world. They also serve as public reminders of the importance of conserving and restoring the Great Lakes. Demand for scientific data has continued to increase while funding for research and monitoring has been reduced, prompting science vessel managers to seek more efficient ways to accomplish their missions. Accordingly, the Council began holding annual Great Lakes Science Vessel Coordination Workshops in 1997 to promote information exchange, sharing of resources and coordination of vessel operations.

8.4.2 Workshops

Continuing its strong support for binational coordination of science vessel operations, the Council hosted The Sixth Annual Great Lakes Science Vessel Coordination Workshop in Cleveland, Ohio in conjunction with Marine Community Day on January 31 – February 1, 2002. Participants were briefed on the latest developments in the implementation of an Automatic Identification System and electronic charting for ships operating in the Great Lakes. The U.S. Coast Guard provided an update on actions being taken to enhance port safety and security, and a variety of presentations were made on available training, vessel maintenance and conversion, and the results of scientific studies that had utilized vessels resources. Science and research success stories were shared and the workshop provided a productive exchange of views. Participants discussed their expectations for future coordination efforts and annual workshops, and highlighted the need to forge ahead on elements of the action plan created in 1997.

The Seventh Annual Science Vessel Coordination Workshop was held at the Holiday Inn Select in Windsor, Ontario on March 13-14, 2003. Following up on issues raised the previous year, the meeting targeted specific goals set out in the action plan and concentrated on agreeing on an organizational identity, defining the mission and vision of the organization, and how to manage activities. A presentation was made on the new science vessel web site and representatives of the U.S. Coast Guard Marine Safety Office in Detroit, Michigan and Canadian Ship Safety led an excellent discussion of vessel manning, safety and inspection requirements. John Tanner, superintendent of the Great Lakes Maritime Academy, described the latest addition to the Great Lakes science vessel fleet, the 224 foot long *State of Michigan* that will operate as a training ship and research vessel from Traverse City, Michigan. In addition, Dr. Jan Ciborowski, professor at the University of Windsor's Great Lakes Environmental Institute of Research and a member of the Council presented an overview of the 2002 Lake Erie Trophic Study, a large scale research effort involving a major commitment of science vessel resources and intensive coordination on both sides of the border. All of the presentations were well received, the new web site was given high marks and a facilitated group discussion helped the workshop participants achieve their objectives.

8.4.3 New Web Site

In response to concerns expressed during The Sixth Annual Great Lakes Science Vessel Coordination Workshop about the ability to communicate needs and coordinate vessel schedules on the science vessel web site, the Council agreed to procure a web host and to initiate improvements to the site. The science vessel web site was completely overhauled and transformed into a web-based database where vessel schedules may be posted, researchers can identify available resources and operators can effectively communicate and exchange information on a wide variety of operational concerns. Operators are now able to directly post information to the site about equipment issues and events; they can access the list server, and can also immediately update vessel data to reflect new equipment or modifications to existing vessels. The public can view information about the Great Lakes science vessel fleet and gain a better appreciation for the scope of work that is being done on both sides of the border. For more information, please visit the new site at: www.glsciencevessels.org.

8.4.4 Focus Areas

Annual workshops provide an excellent forum for exchanging ideas, however it was made clear by workshop participants that meeting the challenges facing managers and operators of Great Lakes science vessels will take more than a once-a-year effort. To achieve the goals set in the 1997 action plan, the value and services the fleet provides needs to be made clear to the public. An advocacy group similar to the University – National Oceanographic Laboratory System, but addressing the special research, training and outreach needs of vessels typically found in the Great Lakes basin, needs to be established. There is a wide variation in the utilization of vessels currently operating in the Great Lakes and standards for manning and inspection of vessels also vary widely. To address these needs, the workshop participants decided to form an organization called the Great Lakes Association of Science Ships. The vision of the organization will emphasize achieving full utilization of all science vessels in the most effective manner and they will concentrate efforts on three focus areas:

- advocacy;
- standards development; and
- marine personnel requirements.

Leads were assigned to each focus area and deliverables listed for 2003-2004. These include promoting the value of science vessel work, further improvements to the web site, developing a standards library and creating a recommended list of training requirements. The next science vessel coordination workshop will be held on February 3-5, 2004 at the Great Lakes Maritime Academy in Traverse City, Michigan. The workshop will concentrate on activities in each focus area, reviewing the status and planning objectives for 2004. The Great Lakes Maritime Academy will be an ideal location to meet and to take advantage of a wide selection of training opportunities.

8.4.5 Recommendation

The Council recommends the following to the IJC:

- **The International Joint Commission continue its strong support for annual science vessel coordination workshops.**

8.5 COUNCIL MEMBERSHIP FOR 2001 - 2003

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