PRIORITIES 2003-2005

Priorities and Progress under the Great Lakes Water Quality Agreement

June 2006

INTERNATIONAL JOINT COMMISSION
Canada and United States

COMMISSION MIXTE INTERNATIONALE
Canada et États Unis

Report to the International Joint Commission

by the

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

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INTRODUCTION

Through the Great Lakes Water Quality Agreement, Canada and the United States (the Parties) have committed "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 is to evaluate the progress of the two governments in implementing the Agreement, identify unmet challenges, provide advice, and recommend solutions. The Commission provides a report at least once every two years presenting its findings, advice, and recommendations to governments.

Priorities

In consultation with its Great Lakes Water Quality Board, Great Lakes Science Advisory Board, International Air Quality Advisory Board, and Council of Great Lakes Research Managers, and also soliciting the views and opinions of basin residents, the Commission establishes priorities for study on a biennial cycle. The studies enhance understanding and offer potential resolution to critical issues faced by the Parties and by citizens of the Great Lakes basin. The Commission's investigations are not a substitute for the work of the Parties, but rather take advantage of its unique independent and binational role under the Agreement.

During 2003-2005, the Commission investigated seven priorities:

- Advice regarding review of the Great Lakes Water Quality Agreement;
- Urbanization;
- Human health;
- Annex 2—Remedial Action Plans and Lakewide Management Plans—of the Great Lakes Water Quality Agreement;
- Atmospheric transport of mercury;
- Great Lakes research strategy; and
- Aquatic invasive species.

In addition to investigating these issues directly, the Commission assigned the priorities to the Boards and the Council according to each group's mandate, expertise, and allocated monetary and human resources. Many priorities were undertaken collaboratively. Some were designed for completion in two years; others are addressed for a longer term.

Reports

This *Priorities Report* for 2003-2005 contains insight and advice developed by the Boards and the Council regarding research, science, and policy that are fundamental for advancing stewardship of the Great Lakes basin ecosystem. This report, we believe, presents compelling arguments for positive actions that will contribute to restoring and protecting the Great Lakes basin ecosystem for the enjoyment and use of present and future generations. In so doing, we are acting in the best interests of our client, the Great Lakes.

The Commission will consider the information and recommendations in this *2003-2005 Priorities Report* as it develops its advice to governments and reports to the public through its forthcoming *Thirteenth Biennial Report on Great Lakes Water Quality,* and other special reports.

The Report's Authors

The Great Lakes Water Quality Board is the principal advisor to the Commission under the Agreement. The Water Quality Board:

- Makes recommendations on the development and implementation of programs to achieve the Agreement's purposes;
- Assembles and evaluates information from those programs;
- Identifies deficiencies in program scope and funding, and evaluates the adequacy and compatibility of results;
- Examines the appropriateness of programs in light of present and future socio-economic imperatives; and
- Advises the Commission on program progress and effectiveness.

The Board's membership includes 20 program managers and administrators from the two federal governments and the eight states and two provinces in the Great Lakes - St. Lawrence River basin.

The Great Lakes Science Advisory Board serves as the scientific advisor to the Commission and the Water Quality Board. The Science Advisory Board 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." The Board's 18 members – nine from each country – represent a broad range of disciplines from the social, physical, and natural sciences. Members are drawn from universities, government institutes and agencies, and private industry.

The Council of Great Lakes Research Managers provides advice regarding Great Lakes research programs and needs. The Council enhances the Commission's ability to provide effective leadership, guidance, support, and evaluation of Great Lakes research, and in particular how this research satisfies the Agreement's requirements and intent. The Council's 24 members include federal, state, and provincial research program managers and representatives from academia, private industry, the Great Lakes Fishery Commission, and the International Association for Great Lakes Research.

Given the significance of the air as a pathway by which contaminants reach Great Lakes waters, the Commission relies on its International Air Quality Advisory Board to provide advice pertinent to airborne issues. Its 10 members are drawn from academia and government institutes and agencies in both countries.

SUMMARY OF RECOMMENDATIONS

The following 28 recommendations were developed by the Great Lakes Water Quality Board, the Great Lakes Science Advisory Board, and the Council of Great Lakes Research Managers. Substantiating details are provided in the full chapters following this summary.

CHAPTER 1 – REVIEW OF THE GREAT LAKES WATER QUALITY AGREEMENT

Principles for Review of the Great Lakes Water Quality Agreement

The Great Lakes Water Quality Board recommends that:

- **The *Principles for the Review of the Great Lakes Water Quality Agreement* be used as a guide for all governmental and nongovernmental activities relevant to the review.**

Science and the Agreement

The Great Lakes Science Advisory Board reiterates the following recommendation from its *1997-1999 Priorities Report* that:

- **The IJC advise the Parties of the importance of traditional ecological knowledge for understanding the Great Lakes basin ecosystem, and the need to develop mechanisms and processes to ensure that the opportunity to contribute such knowledge is fully provided to aboriginal people and their structures of governance.**

Defining a Research Coordination Strategy for the Great Lakes

The Council of Great Lakes Research Managers recommends to the International Joint Commission that:

- **The Parties incorporate a research coordination process involving the Council of Great Lakes Research Managers into a revised Agreement.**

CHAPTER 3 – ANNEX 2 OF THE GREAT LAKES WATER QUALITY AGREEMENT

The Great Lakes Water Quality Board recommends to the International Joint Commission that:

- **Governments identify a Remedial Action Plan coordinator for each Area of Concern at the state, provincial, and/or local level and provide funding to support the position.**
- **Governments provide stable funding for monitoring the appropriate parameters to show progress toward the restoration of beneficial uses.**
- **The Commission help raise the profile of Remedial Action Plans.**
- **The Commission help coordinate meetings and workshops to bring together for mutual education representatives from Areas of Concern, including binational Areas of Concern, dealing with similar issues.**
- **The Commission encourage and foster the science necessary to assist Remedial Action Plan groups with the development of delisting criteria.**

CHAPTER 4 – URBANIZATION

Urban Land Use

The Great Lakes Science Advisory Board recommends to the International Joint Commission that:

- **The Commission, in cooperation with the Parties, state/provincial, municipal, and other regional stakeholders, convene a binational conference to elucidate the extensive data and experience available on the causes of, and potential solutions for, water resource impacts of urbanization in the Great Lakes basin.**
- **The Commission urge the Parties, in partnership with state/provincial and local governments, and**

as a principal outcome of the proposed binational conference, to develop detailed technical guidance for local governments on how to evaluate the suitability of a site for specific recharge-based stormwater management measures.

- **The Commission encourage the Parties to make infrastructure funding contingent on the existence of adequate watershed management and land-use planning processes, including an integrated, cost-effective plan for management of sewage treatment plant outflows, sanitary/combined sewer overflows, and stormwater discharges.**
- **The Commission urge the Parties, through state/provincial agencies as appropriate, to direct agencies that have local planning expertise and responsibility to initiate institutional coordination to limit urban/suburban/exurban development to shared watershed areas where stormwater best management practices and low-impact development can be successfully implemented.**
- **The Commission initiate dialogue involving the Commission, Parties, developers, and financial institutions to explore the environmental implications of urban land-use financing decisions.**

CHAPTER 5 – HUMAN HEALTH

Waterborne Microbial Pathogens in the Great Lakes

The Great Lakes Science Advisory Board recommends to the International Joint Commission that:

- **The Parties create an Environmental Pathogens Strategy, similar to the Binational Toxics Strategy, to establish an inventory of baseline data for the United States and Canada and to undertake a complete analysis of pollution reduction scenarios for key sources and determine their effectiveness in reducing microbial contamination of the waters of the Great Lakes basin.**
- **The Parties invest substantially in research and pilot studies for the removal of pathogens from wastewater treatment plant effluents, environmentally friendly sludge disposal, and strategically upgraded wastewater treatment infrastructure.**
- **The Parties create a waterborne-disease registry for the Great Lakes basin.**

Chemical Exposures and Effects in the Great Lakes Today

The Great Lakes Science Advisory Board recommends to the International Joint Commission that:

- **The Parties target brominated flame retardants, perfluorinated alkylsulfonates (and their salts), and alkylphenols as Level 1 substances under the Binational Toxics Strategy in order to achieve their policy of virtual elimination of the discharge of persistent toxic substances.**
- **The Parties invest in strategies to detect and mitigate the environmental effects of new and emerging contaminants.**
- **The Parties' Binational Executive Committee adopt a binational approach to the use of the precautionary principle in the management of chemicals in the Great Lakes basin.**
- **The Parties accelerate the removal of severely contaminated sediment from Areas of Concern.**
- **The Parties modify their fish consumption advice to address overall fish consumption to focus on:**
    - **Developing a single advisory that addresses both lipid-soluble contaminants such as PCBs, dioxins, and pesticides as well as methylmercury;**
    - **Providing readily accessible information that is linguistically, culturally, and economically appropriate;**
    - **Reaching the most vulnerable populations;**
    - **Promoting special precautions for pregnant women including effects on the fetus, women of child-bearing age, and children under 15, and advocating that this group adopt the additional prudence of not eating Great Lakes fish as an option; and**
    - **Providing information on nutritionally equivalent alternatives to fish.**
- **The Parties conduct a thorough and transparent benefit-cost analysis of mercury emissions to the Great Lakes environment, including impacts on the health of humans and wildlife, lost economic activity to sport and commercial fishing, as well as the costs of controlling emissions from coal-fired power plants, chloralkali plants, and other sources and remediating mercury contamination.**
- **The Parties undertake human health-effects research focusing on multi-media exposure due to place of residence, with consideration of non-cancer effects such as heart and respiratory disease, diabetes, and endocrine, reproductive, and neurological disorders.**

CHAPTER 7 – COUNCIL OF GREAT LAKES RESEARCH MANAGERS

The Council of Great Lakes Research Managers recommends to the International Joint Commission that:

- **The Parties insert language into a revised Agreement that provides for coordination of United States and Canadian participation in the Great Lakes portion of the Global Earth Observation System of Systems.**
- **The Commission actively support and participate in the implementation of the Great Lakes portion of the Global Earth Observation System of Systems and promote widespread binational participation from all agencies and organizations.**
- **The Parties encourage organizations that grant funds for Great Lakes research to routinely use the Great Lakes – St. Lawrence Research Inventory as a tool to evaluate research proposals, avoid duplication of efforts, and to help identify existing programs that could contribute expertise and effectively use research dollars.**
- **The Commission maintain its support and funding for science-vessel coordination workshops sponsored by the Council of Great Lakes Research Managers to improve communication regarding vessels, and facilitate their coordination and use.**
- **The Parties significantly increase their investment in Great Lakes research, scientific technology, and research vessel fleet modernization to support the goals of the Agreement.**

Chapter One

REVIEW OF THE GREAT LAKES WATER QUALITY AGREEMENT

PERSPECTIVE

Pursuant to Article X of the Great Lakes Water Quality Agreement, the governments of Canada and the United States (the Parties) are required to undertake a review of the Agreement following transmittal of the International Joint Commission's *Twelfth Biennial Report on Great Lakes Water Quality*. The Commission tendered its report in 2004.

For more than 30 years, the Agreement has played a pivotal role in restoring and protecting the Great Lakes Basin Ecosystem. Under terms of the Agreement, the Commission assesses progress and assists both federal governments in achieving the Agreement purpose "to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem." The Commission recognizes that scientific knowledge and ecological conditions have changed dramatically since the first Agreement was signed in 1972. Therefore, the Agreement may need updating to be meaningful for achieving Agreement goals and to address new challenges to the entire basin ecosystem.

THE COMMISSION'S DECLARATION

In keeping with its role and obligations under the Agreement, the Commission issued a Great Lakes Declaration at the conclusion of its 2003 Great Lakes Conference and Biennial Meeting in Ann Arbor , Michigan. It declared that it would:

- Make assisting the governments of the United States and Canada in their review of the Agreement a top Commission priority.
- Engage the public in active dialogue and make the advice it gives to governments regarding the Agreement's review transparent and open to input from all who care about the health of the Great Lakes basin ecosystem.
- Facilitate public participation in the review process by involving stakeholder organizations such as environmental and conservation groups, industry and trade associations, and riparian interests through a variety of mechanisms.
- Listen to and consider the broadest possible array of perspectives on the nature of the Agreement's review in preparing advice to governments.
- Urge the governments of the United States and Canada to be thorough, visionary, and far-reaching as they review the Agreement and to address critical questions regarding its scope, the role of the Commission, and emerging issues not currently included in the Agreement.
- Consider and recommend to the governments the reporting requirements necessary to track progress, the mechanisms needed for effective implementation, and the observing systems needed to gather critical information about ecosystem health.
- Encourage the governments to fully consider linkages between review of the Agreement and adoption of lake restoration initiatives in both countries.
- Release a special report detailing its advice to governments on the review of the Agreement.

The full declaration is available at http://www.ijc.org/rel/comm/030920-declaration_e.htm.

THE COMMISSION'S PRIORITIES

In keeping with its Declaration, the Commission has undertaken a number of activities to assist the Parties in their review of the Agreement. Among its activities, the Commission assigned

For more than 30 years, the Agreement has played a pivotal role in restoring and protecting the Great Lakes Basin Ecosystem.

two priorities to its advisory boards, one broad and one with a specific focus. The broad priority enlists the boards' assistance in carrying out the elements of the Commission's Declaration to assist the Parties with the Agreement's review. The specific priority focuses on developing a Great Lakes research strategy.

Review of the Agreement: To assist the Parties with the review, the Commission committed to:

- Provide comments on the purpose of the Agreement;
- Consult broadly with the public and with stakeholders;
- Examine state-of-the-art science on Great Lakes ecosystem stressors and the ability to address such stressors under the current Agreement;
- Explore opportunities for program and policy reform and how such reform might be made operational by the Agreement;
- Review research management and coordination related to the Agreement;
- Provide advice on institutional arrangements to improve implementation of the Agreement;
- Suggest an open and transparent process to engage a broad cross section of the public in the review; and
- Assess which annexes would benefit from updating and how that might be done most effectively.

Great Lakes Research Strategy

The Commission, the U.S. General Accounting Office, and the Canadian Auditor General have highlighted the disjointed approach to Great Lakes research and the need for coordination and leadership. To provide advice directly related to Annexes 11 and 17 of the Agreement, the Council of Great Lakes Research Managers committed to develop an overarching research strategy that provides a framework for binational and regional collaboration. The strategy also outlines how to engage individual agencies in the United States and Canada and how to bring widespread resources to address large-scale coordinated research needs.

Because research and monitoring are inextricably tied together, the Council also worked with the Great Lakes Commission to develop a Great Lakes Observing System, and explored the feasibility of holding a large-scale, lakewide research project to test the effectiveness of the strategy.

The Council believes the Agreement can provide a binational strategy for research coordination. Accordingly, the Council proposed to bring together top administrators from the academic community, government agencies, and business leaders to identify portions of the Agreement related to research that could be strengthened, and to produce a recommended binational research coordination strategy.

The remainder of Chapter One presents advice and insight to the Commission from the Great Lakes Water Quality Board, the Great Lakes Science Advisory Board, and the Council of Great Lakes Research Managers to the Commission regarding review of the Agreement and development of a Great Lakes research strategy.

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Agreement Review

1.1 Overview

At the International Joint Commission's 2003 Great Lakes Conference and Biennial Meeting in Ann Arbor, Michigan, the Commission delivered a "Great Lakes Declaration." As required after they received the Commission's Twelfth Biennial Report in 2004, the Declaration encourages a thorough review of the Agreement by governments, to address new challenges to the Great Lakes ecosystem. Moreover, the Declaration states that the International Joint Commission (IJC) intends to play a role in the review and would release a special report to governments. Consequently, the IJC charged its Agreement boards and council with "advice on Agreement review" as their top priority during 2003-2005.

As the IJC's senior advisory body, the Great Lakes Water Quality Board (WQB) served as liaison on all Agreement boards and council activities for the Agreement's review and undertook specific activities of its own. The WQB's first action was to develop a set of principles that provide guidelines for the IJC, governments, and nongovernmental organizations to follow when undertaking activities and programs relevant to the Agreement review. Next, the WQB conducted a retrospective analysis of the main issues and drivers involved in the original 1972 Agreement, the revised 1978 Agreement, and the 1987 revisions by protocol. This analysis was conducted with the recognition that it is often best to look back into history before moving forward.

The WQB was also involved in several activities regarding the Agreement's scope. The purpose of the Agreement (Article II) espouses an ecosystem approach to restoring the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem. The WQB reviewed the ecosystem approach in an attempt to clarify what is sometimes viewed as an ambiguous concept, and also addressed the fact that the Agreement is primarily a "chemical integrity" document with "physical integrity" mentioned only in Article II, and "biological integrity" only briefly in terms of aquatic invasive species in Annexes 6 and 17. The WQB reported on aquatic invasive species in 2001 and the report is available at: http://www.ijc.org/php/publications/html/ais01may.html. The WQB addressed physical integrity in this 2003-2005 cycle.

Finally, the WQB recognized that the eight Great Lakes states and the province of Ontario are intensively involved in watershed planning activities throughout the Great Lakes basin. Therefore the WQB held a Watershed Approaches Workshop in March 2005 to explore how linkages could be improved between jurisdictional watershed planning activities and the lakewide management plans called for in Annex 2 of the Agreement.

Principles for Review of the Great Lakes Water Quality Agreement

1.2 Introduction

The Parties are responsible for the overall review of the Great Lakes Water Quality Agreement. The WQB completed its *Principles for the Review of the Great Lakes Water Quality Agreement* in April 2004. After making minor editorial revisions, the IJC submitted the document to the Parties in June 2004, with the recommendation that the Parties adhere to the principles while conducting their Agreement review. The principles are summarized below, and are organized according to Article X.4, which states "the Parties shall conduct a comprehensive review of the operation and effectiveness of the Agreement." The full document is available at http://www.ijc.org/php/publications/pdf/ID1566.pdf.

1.3 Operation and Effectiveness

The process of conducting the review should be:

- **Open and transparent** – To the extent practicable, deliberations should be open and transparent and part of the public record.

- **Inclusive** – A full range of views and perspectives should be solicited throughout the basin through a variety of means (*e.g.*, meetings, workshops, and websites). A wide spectrum of groups and individuals, including those not normally part of Agreement activities and discussions, should be engaged to determine whether the Agreement is meeting the needs of the people of the Great Lakes basin.

- **Timely** – This opportunity for widespread community support for a review, as seen in the renewal of the Great Lakes Programme in Canada and the proposals for a restoration program in the U.S., should be capitalized on. Timely onset of the review is as important as a reasonable time frame for completion. The review should also be of sufficient length to obtain necessary information and viewpoints while at the same time short enough to minimize "burnout." A time frame of 18 months is suggested.

- **Binational –** Work groups or teams should have an equal number of members from both countries. Consultations should allow equal opportunities for citizens of both countries to voice their opinions.

- **Impartial –** The review should be impartial and avoid conflict of interest. While all players in the basin have a vested interest in maintaining certain roles and responsibilities, organizations should be open to the review – by others – of their own role and work.

1.4 Comprehensiveness

The Agreement's comprehensive review will address, by necessity, substantive issues within the Agreement. Principles for guiding a comprehensive review should:

- **Consider the purpose of the Agreement first –** In order for the review process to be most efficient, the purpose of the Agreement should be confirmed first before taking a more in-depth look at the articles and annexes of the Agreement.

- **Use science and science-policy linkages as the basis for the review –** The review should be guided by scientific evidence regarding what action is needed to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem. The concepts of sustainable development, the ecosystem approach, virtual elimination, and zero discharge of persistent toxic substances should be affirmed. Moreover, while the importance of a sound scientific basis for conclusions and recommendations should be emphasized, it may sometimes be necessary to adopt a precautionary approach and act even in the absence of a scientific consensus where prudence is essential to protect public welfare.

> ... it may sometimes be necessary to adopt a precautionary approach and act even in the absence of a scientific consensus where prudence is essential to protect public welfare.

- **Be forward looking –** Consider the relevance of existing articles and annexes, as well as any new issues, for possible additions that are aligned with the Agreement purpose. The goals, objectives, and end points in the Agreement should serve as drivers for action.

- **Address governance –** In order to maximize a sense of ownership throughout the Great Lakes community, consider the governance roles, responsibilities and relationships of those implementing the Agreement, including the Parties' interactions with First Nations, tribes, states, provinces, municipal and regional governments, and nongovernmental organizations. Consider the roles and effectiveness of organizations created under or implementing the Agreement (*e.g.*, the IJC together with its Great Lakes Regional Office, the Water Quality Board, the Science Advisory Board, and the Binational Executive Committee.) Clarify, as necessary, how the Agreement relates to other basin organizations such as the Commission on Economic Cooperation, Great Lakes Fishery Commission, Great Lakes Commission, and Council of Great Lakes Governors.

- **Enhance accountability –** As each element in the Agreement is being reviewed, the Parties should consider how to enhance accountability to the public for implementation of the Agreement by the Parties, states, and provinces, as well as by cooperating stakeholders in the Great Lakes basin ecosystem.

1.5 Recommendation

- **Recognizing that the Agreement review will entail informal and formal activities by government and nongovernmental organizations, the WQB recommends that the *Principles for the Review of the Great Lakes Water Quality Agreement* be used as a guide for all governmental and nongovernmental activities relevant to the review.**

History of the Great Lakes Water Quality Agreement

1.6 Introduction

In discussions with public resource managers and policymakers, WQB members noted that often there was little understanding of the history of the Great Lakes Water Quality Agreement, why it was established in 1972, and what main issues were involved in its subsequent revisions in 1978 and 1987. The WQB determined that information on the history of the Agreement would be helpful so that the Great Lakes community better understands the influences from which the current Agreement emerged. Understanding the main impetus for change is an integral step in assessing the Agreement's current relevance and providing a benchmark for the Agreement's review. Historian Dr. Jennifer Read of Michigan Sea Grant Program completed a report to the WQB, including a bibliography of pertinent publications, which reviewed the literature. She also interviewed key individuals involved in each phase of the Agreement's creation, review and revision. Excerpts from Dr. Read's report follow.

1.7 Background and Context

The Boundary Waters Treaty of 1909 and the role it authorized for the International Joint Commission (IJC) form the legal and institutional foundation upon which the Agreement is based. The Treaty enumerated rules for developing shared water resources between Canada and the United States including:

- An order of precedence for the use of boundary waters;
- Freedom of navigation on the Great Lakes for U.S. and Canadian citizens;
- Equal access to the court system of each country for citizens injured by a riparian action from the other side; and
- IJC authorities to approve, amend, or deny activities that affect the natural level or flow of boundary waters or water crossing the boundary.

In Article IV, the Treaty also obliged both countries to avoid polluting the water on one side of the boundary to the injury of health or property on the other. The Treaty assigned the IJC advisory, quasi-judicial, and arbitrational roles related to various aspects of boundary water management.

The 1972 Great Lakes Water Quality Agreement was the culmination of almost 70 years of work on Great Lakes water quality under the auspices of the Treaty. The first reference the Parties assigned to the IJC in 1912 was to investigate pollution in boundary waters. In its 1918 report, the IJC recommended that the two governments create another treaty to specifically address boundary waters pollution. The Parties asked the IJC to draft such a document, and the IJC presented a draft treaty in 1926. The draft assigned the IJC authority to investigate any activity potentially in contravention of Article IV of the Treaty including failure to act. If the IJC found such activity, the two countries were then obliged to act against those determined to be in contravention of the Treaty. A combination of factors aligned to prevent the draft treaty from being ratified, including the widespread introduction of chlorinated municipal water supplies, which removed the pressure for action that previously rampant cholera and typhoid epidemics had instilled, and the Great Depression, which distracted decision makers with issues other than those affecting water quality.

In 1941 the Canadian government expressed interest in the abandoned draft treaty. Both governments asked the IJC to update the data from the 1918 report as a prelude to reconsidering the 1926 convention. The IJC found that boundary water pollution had not declined during the intervening years; in fact, the Great Lakes connecting channels were even more polluted than they had been earlier. However, interest in another treaty waned and the IJC's 1950 report stopped short of recommending an increase in its role. Instead the IJC advised the two countries to adopt common water quality standards for the connecting channels and that their implementation be supervised by appointed technical advisory boards. This led to the Parties adopting common standards in 1951. Soon thereafter, the rapidly deteriorating condition of lakes Erie and Ontario pointed to the need for further study to update the status of the lakes themselves. In 1964, the two governments sent a pollution reference to the IJC for the lower lakes and the international section of the St. Lawrence River. This time the IJC recommended that its role be expanded, and the Parties endorsed and incorporated this into the 1972 Agreement.

The 1972 Great Lakes Water Quality Agreement was the culmination of almost 70 years of work on Great Lakes water quality under the auspices of the Treaty.

1.8 The 1972 Great Lakes Water Quality Agreement

The 1972 Agreement identified common water quality objectives with programs to implement them, compatible standards, and monitoring procedures. It established the WQB and the Great Lakes Research Advisory Board (later renamed the Science Advisory Board, or SAB), and a regional office in Windsor, Ontario to carry out this work. The Agreement also included two references, one to examine pollution from land use activities and the other to investigate pollution in the upper lakes.

The Agreement's purpose was to address eutrophication problems as identified in the IJC's lower lakes report of December 1970. While primarily focused on reducing phosphorus inputs associated with municipal wastewater plants, the Agreement also required that serious bacteriological contamination be eliminated in nearshore areas and addressed some key toxic contaminants as well as oil and other spills in the Great Lakes. Much of the non-phosphorus content would be revised and strengthened under subsequent revisions. For the phosphorus-related activities outlined in Annex 3, the governments agreed to focus initially on detergent phosphates and municipal wastewater treatment as ways to reduce phosphorus pollution. This was due to both the general knowledge that these were significant sources of phosphorus and the lack of clear understanding of the contribution from land-use practices such as agriculture.

1.9 The 1978 Great Lakes Water Quality Agreement

The 1978 Agreement expanded the scope and extent of its 1972 predecessor by broadening the focus from phosphorus reduction, expanding efforts to control toxic contaminants, and explicitly extending the Agreement's scope to all five Great Lakes. In the preamble, the governments introduced the term "Great Lakes Basin Ecosystem" by recognizing that "restoration and enhancement of the boundary waters cannot be achieved independently of other parts of the Great Lakes Basin Ecosystem with which these waters interact." For the first time the Agreement also stated that its purpose was to "restore and maintain the physical, chemical, and biological integrity" of the waters of the Great Lakes Basin Ecosystem. The 1978 Agreement committed Canada and the United States to the virtual elimination of the input of persistent toxic substances and expanded the list of toxic chemicals for priority action. The Agreement also acknowledged that certain areas were not in compliance with some specific objectives and they would likely not be in the short term. This led to the addition of the concept of limited-use zones that were precursors to Areas of Concern (AOCs). In short, the major shifts from the 1972 Agreement to the 1978 Agreement were to add humans as an integral component of the basin ecosystem and to more explicitly recognize the basin "watershed" in restoring the lakes.

1.10 The 1987 Protocol

Per Article X, in 1986 the IJC's third biennial report on Agreement progress triggered the formal Agreement review process. At that time there was concern that revision of the Agreement's body, *i.e.,* the Articles, might weaken the document. This compelled the Parties and others to restrict substantive changes to the annexes and make only limited changes to the Articles that directly related to annex revisions. Revisions focused on providing a management framework to connect programs and objectives as outlined in both the 1978 Agreement and the revised annexes, and providing technical modifications in the form of new or modified annexes. The most significant revisions were made to Annex 2, which was completely re-written. The concept of limited-use zones was replaced with the idea of AOCs, and remedial programs for both AOCs and the open lakes were proposed in Remedial Action Plans (RAPs) and Lakewide Management Plans (LaMPs) for critical pollutants, respectively.

1.11 The Ecosystem Approach

There has been debate about what the ecosystem approach means within the context of the Agreement. Some assert that in order to meet the Agreement's purpose of improved water quality, policymakers and natural resource managers must focus on all components of the ecosystem. This is more than a multi-media approach to water quality, asserting instead that all ecosystem elements are equally important to ensuring water quality. This perspective is in line with a 1980 report by the Great Lakes Science Advisory Board, and the 1985 report of the National Research Council of the United States and the Royal Society of Canada.

Others argue that the Agreement, as written in 1978 and amended in 1987, focuses on water quality solely as it is affected by chemical, physical and biological agents. Therefore, as desirable and necessary as they might be, management activities that address other stressors only serve to divert resources and dilute Agreement implementation. The inclusion of LaMPs in Annex 2 appears to contradict a focus on a broader ecosystem approach by narrowly focusing on critical pollutants. Whether critical pollutants could include non-chemical components that led to the destruction of habitat was never resolved, but one U.S. Environmental Protection Agency (EPA) negotiator noted at the time, "the inclusion of habitat as a beneficial use helped provide the basis for a broader ecosystem view." The first general principle in Annex 2 does call for an ecosystem approach, and 1987 negotiators believed that while the first round of LaMPs might focus only on critical pollutants, public pressure would ensure that subsequent iterations would have a broad ecosystem focus.

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Ecological Integrity and the Ecosystem Approach

1.13 Introduction

The terms "integrity" and "ecosystem approach" are used in Article II and Annex 2, respectively, of the Great Lakes Water Quality Agreement. However, the lack of definition in the Agreement for the term "ecosystem approach" has led to uncertainty and confusion that has adversely affected Agreement implementation. To help provide clarity, direction, and focus, the Great Lakes Water Quality Board (WQB) has compiled definitions of "integrity," "ecosystem approach," and related terms to assist the IJC, the Parties, and others involved in the review of the Agreement.

In its simplest form, ecological integrity is the summation and integration of physical, chemical, and biological integrity as stated in the purpose of the Agreement (Article II). Throughout its history the Agreement has remained predominantly a "chemical integrity" document with considerable detail on nutrients (especially phosphorus) and toxic substances. Major components of biological integrity are biodiversity (not mentioned in the Agreement) and alien invasive species (only briefly mentioned twice, in Annexes 6 and 17). Physical integrity is not mentioned explicitly and is implied only in the loss of fish and wildlife habitat (one of the beneficial use impairments in Annex 2) and loss of wetlands (Annex 13).

The term "ecosystem" is flexible. It can refer to a water body (*e.g.,* Lake Superior, St. Lawrence River), a river or lake basin (*e.g.,* the Detroit River, Lake Erie basin), a drainage area (*e.g.,* watershed), a unit of land (*e.g.,* forest, wetland, urban or rural landscape), or an integration of plants, wildlife, humans, and their living communities and surrounding environment in a specific geographic area (*e.g.,* Niagara Peninsula, Hamilton Harbour AOC), or the entire biosphere. In terms of the interests and obligations of the Parties and IJC under the Boundary Waters Treaty and the Agreement, the basin is a huge and complex ecosystem composed of various interacting elements of the hydrosphere (*e.g.,* surface and groundwater, wastewater, rain, fog), atmosphere (*e.g.,* air, sunlight, wind, smog), lithosphere (*e.g.,* soils, rocks, minerals, sediments), and biosphere (*e.g.,* plants, animals, fish, wildlife, humans). Moreover, a realistic account of the ecosystem in the basin must include specific human activities such as dredging of contaminated sediments and fisheries policy implementation.

> The WQB presents here the definition of 21 key concepts and terms, and the Science Advisory Board presents definitions for nine terms in Chapter 1.22.3

1.14 Ecological Integrity

Ecological integrity is the ability of the ecosystem to maintain its organization and continue its process of self-organization and development. It is the combination of chemical integrity, physical integrity and biological integrity within the ecosystem.

1.15 Glossary of Ecological Integrity, Ecosystem Approach, and Related Terms

An effective Agreement requires a clear understanding of key concepts and consensus on the definition of key terms. The WQB presents here the definition of 21 key concepts and terms, and the Science Advisory Board presents definitions for nine terms in Chapter 1.22.3, below. Our intent is not to provide agreed-upon definitions but, rather, to stimulate dialogue. If concepts and terms are deemed important within the context of the review of the present Agreement and development of a revised Agreement, then the Boards' material will serve as an effective point of departure. Possible differences in the Boards' definitions provide a different "take" on a term or concept and allow for a broader perspective and understanding.

Adaptive management: A type of natural resource management that implies making decisions as part of an ongoing process. Continuously monitoring the results and feedback of an action provides a flow of information that may indicate the need to change or maintain actions. Scientific findings and the needs of society may also indicate the need to adapt resource management to new information.

Biodiversity (biological diversity): The number and abundance of species found within an ecosystem. It includes the variety of genes, species, varieties, and the ecological processes that connect everything in the ecosystem.

Biological integrity: The ability to support and maintain a balanced, integrated adaptive assemblage of organisms sharing species composition in the natural habitat of a given region or ecosystem.

Biosphere: Relatively thin life-supporting stratum of the earth's surface; the global ecosystem that can be sub-divided into regional or local ecosystems.

Best management practices: Methods determined or designed to be the most effective, feasible, and practical means of preventing or reducing environmental pollution from nonpoint sources and natural resource exhaustion in an ecosystem.

Chemical Integrity: The dynamic interaction of natural and manmade chemical substances, whereby various chemicals and combination of chemicals do not adversely impact organisms including humans.

Cumulative effects: Effects of environmental pollution or natural resource stresses that result from separate, individual actions that, collectively, become significant over time.

Ecological integrity: The ability of the ecosystem to maintain its organization, structure, function, and health as well as continue its natural processes of self-organization. Ecological integrity is an integration of biological, chemical, and physical integrity.

Ecosystem: A natural unit of living (biotic) and non-living (abiotic) things and the forces that move among them. Living things are plants and animals, including humans. Non-living parts may be water, air, soils, sediments, rocks, and minerals. All elements are interconnected and interact. Managing any one resource may affect others in that ecosystem. Ecosystems can be small—a single stand of aspen—or large—an entire watershed or wetland, including hundreds of forest stands across many different ownerships.

Ecosystem approach: A strategic and adaptive method for sustainable and comprehensive thinking, planning, and management for protecting or restoring natural ecosystem components, functions, and values. It broadly considers all environmental and natural resources within the ecosystem (*e.g.,* the Great Lakes basin ecosystem) as well as their interactions and cumulative effects on the ecological, social, and economic health, and sustainable development of the ecosystem communities.

Ecosystem health: The physique of an ecosystem. A healthy ecosystem is stable and diverse, resilient and resistant to environmental changes and resource stresses. It is characterized by a state of dynamic equilibrium in its composition, structure, and functions; good maintenance of its physical, chemical, and biological components and their interrelationships for biological diversity and ecological integrity over time. A healthy ecosystem provides abundant and beneficial services, such as food, water, shelter, economic livelihood, recreation, and natural beauty, to its constituents.

Ecosystem management: An ecological approach to environmental and natural resource management to enhance diversity, integrity, and health of the ecosystem by blending environmental, social, and economic needs and values.

Ecosystem sustainability: The long-term ability of an ecosystem to maintain its proper components, ecological processes and functions, biological diversity, and productivity for present and future generations.

Environment: All the external factors, conditions, and influences that affect an organism, a community, or an ecosystem.

Great Lakes-St. Lawrence River basin: The drainage area of the Great Lakes-St. Lawrence River system from Lake Superior downstream to the Gulf of St. Lawrence. Within the context of the Agreement, the drainage basin of the St. Lawrence River is included from Lake Ontario to Cornwall, Ontario/Masenna, New York where the river is the international boundary between Canada and the United States.

Great Lakes-St. Lawrence River ecosystem: The ecological system of water, air, land and biota, including humans, in the Great Lakes-St. Lawrence River basin.

Physical Integrity: Sustainable natural processes, pathways, and landscapes that maintain and improve Great Lakes water quality and quantity, and support natural biodiversity and ecosystem function.

Sustainability: Achieving and maintaining a balance between the human need to improve well-being on one hand, and preserving and restoring natural resources and ecosystems, on which we and future generations depend. Sometimes called "sustainable development" or in the spirit of achieving balance, "environmentally sustainable economic development."

Water-quality approach: A narrower perspective, in comparison with the ecosystem approach, aimed at managing water quality in the Great Lakes by setting objectives for certain chemicals in water based on the most sensitive uses of that water. It does not take full account of interactions within the ecosystem or of stressors external to water.

Watershed: The region draining into a river, river system, or body of water. This is the hydrologic delineation of a watershed, and in the context of watershed planning, the definition often is broadened to include the functional, ecological, cultural, and aesthetic values of the specified geographical unit.

Watershed approach: A coordinated framework for environmental and natural resource management that focuses all stakeholder efforts on the highest-priority problems within hydrologically defined geographic areas (*i.e.,* watershed). It requires the involvement of all stakeholders in the watershed and embodies cyclical management for assessment, planning, management, implementation, and monitoring as iterative processes driven by continuous evaluation, adjustment, and adaptation.

Linking Watershed Management Plans and Lakewide Management Plans

1.16 Introduction

A watershed may be defined as the entire catchment area (drainage basin) that is drained by a watercourse and its tributaries, including land and water with their associated physical, chemical, and biological properties. Within the Great Lakes-St. Lawrence River basin, there are 186 watersheds, 80 in Canada and 106 in the U.S. Their drainage areas range in size from 340 to 25,605 square kilometres, with the average of 3,868 square kilometres. This extensive and complex ecosystem supports various human and environmental functions for more than 34 million people.

Watershed management provides a common understanding of natural ecosystems—their significance, how they relate to one another, whether they are healthy or degraded, and whether realistic opportunities exist for improvement. Thus watershed management may be considered an ecosystem-based approach to managing human activities for the use and conservation of natural resources in the drainage area.

Numerous watershed initiatives are underway or in development in the Great Lakes basin that involve all levels of government, conservation authorities, and nongovernmental organizations. Some are being undertaken pursuant to the Great Lakes Water Quality Agreement, but the Agreement currently is not a major impetus for watershed planning in the Great Lakes basin.

1.17 Watershed-Based Planning and the Agreement

While the Agreement recognizes the importance of adopting an ecosystem approach to improving water quality in the basin, it does not fully address watersheds and the watershed approach. The link between a watershed-based approach and the Agreement is briefly discussed in Annex 13 (Pollution from Non-Point Sources), which requires the Parties to:

> "Develop and implement watershed management plans, consistent with the objectives and schedules for individual Remedial Action Plans or Lakewide Management Plans, on priority hydrologic units to reduce non-point source inputs. Such watershed plans shall include a description of priority areas, intergovernmental agreements, implementation schedules, and programs and other measures to fulfill the purpose of this Annex and the General and Specific Objectives of this Agreement. Such measures shall include provisions for regulation of non-point sources of pollution." (Annex 13, 2b).

Watershed planning is underway in jurisdictions throughout the Great Lakes basin, but it appears that the Agreement and specifically Annex 13 have not been the major impetus for these planning activities. In contrast, Annex 2 is the major driver for Remedial Action Plans (RAPs) in the Areas of Concern (AOCs) and Lakewide Management Plans (LaMPs). Most AOCs are located in the lowest part of watersheds closest to the Great Lakes (*e.g.*, tributary mouths, embayments, and the connecting channels). The review of the Agreement provides an opportunity to assess the structure and role of RAPs and LaMPs, and how the use of watershed planning approaches (municipal, regional urban, and regional rural) as implemented by various organizations and jurisdictions can be better linked with RAP and LaMP activities, thus providing a more holistic, ecosystem perspective to restoration and protection initiatives.

1.18 Watershed Approaches Workshop

1.18.1 Workshop Intent

Because local and regional watershed planning initiatives are being pursued in a manner somewhat disconnected from Agreement programs, the IJC's WQB convened a Watershed Approaches Workshop in Ypsilanti, Michigan on March 8-9, 2005 to promote information sharing among water quality managers working throughout the basin. Participants also identified issues and challenges in watershed planning across the basin, and exchanged ideas and experiences. The workshop also sought to:

- Promote dialogue and mutual understanding among authorities responsible for water quality and watershed planning and management in the basin.
- Develop a clear sense of opportunities for enhanced collaboration among LaMP and local/regional watershed planning managers. In this regard, the workshop represented a scoping or problem-setting exercise, wherein the WQB could encourage and promote a more consistent approach to improving water quality throughout the basin.
- Facilitate an initial and ongoing exchange of information that can assist the WQB in developing advice regarding the review of the Agreement.
- Plot a provisional course of actions (*i.e.*, pragmatic next steps) to nurture opportunities for enhanced collaboration.

The workshop sought to gather advice from participants working on watershed initiatives across the basin for the purpose of achieving the objectives given above. The information gathered is intended, in part, to inform the WQB's advice to the U.S. and Canadian governments regarding their joint review of the Agreement.

Watershed-based planning approaches are being applied in all areas of the basin. Key challenges, therefore, lay in fostering greater collaboration between and among the many agencies and organizations pursuing such initiatives and integrating the different approaches being utilized. Accordingly, the workshop sought to examine those challenges and, by extension, explore what initiatives are occurring in the basin, how they are being undertaken in the context of the Agreement, and identify whether there are opportunities for better protecting the Great Lakes system through enhancements of the Agreement.

1.18.2 Workshop Format

While RAPs and regional plans developed under the Agreement are important to restore and protect the Great Lakes basin, the workshop primarily focused on jurisdictional watershed programs and LaMPs. The format was developed to maximize information sharing, discussion and interaction among participants, who were invited based on their experience and expertise in watershed initiatives. Presentations addressed federal, state, and provincial watershed programs, perspectives on the LaMP process, and watershed governance.

1.18.3 Summary of Workshop Findings

Overall, participants agreed that much more could be done to better relate LaMP initiatives and local/regional watershed planning initiatives to each other. Several participants described LaMPs as works in progress, while others felt that the LaMP initiative has not lived up to its promise. One participant asked if all watershed planning initiatives should be subsumed under a LaMP. Others suggested that initiatives pursued outside of an Area of Concern (AOC) tend not to have much connection to LaMPs.

Participants also raised the challenges associated with communicating watershed concepts, including the LaMP initiative, to the general public. Some were uncertain about the purpose of LaMPs, while one participant saw LaMPs as blueprint planning documents rather than for use with the general public. Participants felt that the role of LaMPs needs to be clarified as to how they relate to the public.

Regarding the relationship between LaMPs and lower- and upper-tier watershed planning initiatives, several participants believe that LaMPs reflect a command-and-control approach. Some felt that fragmentation of authority and mandates forces agencies to focus on single issues rather than integrated approaches such as watershed planning. Overall, the general view was that much more could be done to better relate LaMP initiatives and local/regional watershed planning initiatives to each other.

1.18.4 Emerging Gaps Regarding Improving Linkages

Participants noted key gaps to improving linkages among LaMPs, RAPs, and jurisdictional watershed planning efforts. Gaps were characterized as drivers, flexibility and adaptability, collaboration, research needs, governance issues, funding, and overall water quality planning.

Drivers

Drivers that influence watershed planning initiatives at local and/or basinwide levels are:

- regulations
- nonpoint source pollution
- stormwater management
- urban sprawl
- toxic contaminants
- drinking-water protection
- flood and drought management
- eutrophication

Flexibility and Adaptability

Watershed planning in the U.S. is largely driven by statute and regulations, as evidenced by the scope and intent of the U.S. Clean Water Act. Several participants commented that regulations limit flexibility for how watershed plans are developed and implemented. The Ontario approach which is less prescriptive and has more latitude for development of consensus approaches and solutions is more flexible than the U.S. approach.

While attention to certain issues – among them water quantity and habitat protection – is prescribed by regulation, participants embraced the notion that each watershed must be recognized as different and therefore unique. Accordingly, the watershed should dictate what is required in terms of a focus for planning and action. Flexibility and adaptability in watershed planning accommodates these differences and encourages collaborative efforts across the basin.

Collaboration

Collaboration emerged as an overarching issue. A common sentiment expressed was the need for improved collaboration between and among all parties undertaking watershed-planning initiatives in the basin.

However, several participants shared the view that there are disincentives to promoting and nurturing greater collaboration. Bureaucratic issues, including the potential loss of jobs and competition for funding resources, were highlighted. Inflexible regulatory requirements can act as disincentives to engage in watershed planning, and can act as economic disincentives as well.

Research Needs

While research on the Great Lakes basin has been in place for several years in the form of aquatic science, research areas that deal with other interrelated issues facing the basin's land areas have not been incorporated to provide a true watershed perspective. Other research areas, such as agricultural science and industrial ecology, are also relevant to watershed and aquatic research in the basin. In addition, there is no universal way to measure progress in watershed planning initiatives because common measurements have not been established.

Governance Issues

Some participants felt that centralized planning with direction and action imposed from above or from "outsiders" who may not fully understand or appreciate local or on-the-ground issues does not work with regard to roles and responsibilities and available resources. Rather, the local level has to be relied upon because the challenge of environmental protection and remediation often rests on local communities and local planning institutions. Responsible parties are often reluctant to take ownership of a problem, and participants suggested that perhaps each jurisdiction should take responsibility for their share of a particular issue. Scale is also important as is the need to establish clear demarcation of responsibility.

Funding

Greater funding is needed in order to achieve the objectives of watershed planning initiatives. Integration of resources was emphasized to maximize program efficiency, including the pooling of funding and/or funding requests. Economic and social incentives were suggested to encourage support for and participation in watershed initiatives. Overarching grant programs were viewed as a beneficial driver, and a more effective use of grant programs was recommended.

Overall Water Quality Planning

Participants advised that the Agreement be made more comprehensive in scope. While the Agreement is designed for open lake waters, the Agreement's overall approach does not adequately address land and nearshore issues. Other issues and considerations should also be included in the Agreement, such as groundwater issues when dealing with the physical integrity of a lake ecosystem.

1.18.5 Conclusions

Key outcomes from the workshop include:

- Identification of a clear need for better coordination and collaboration between and among planning initiatives undertaken at different jurisdictional levels, *i.e.*, between local initiatives and LaMP initiatives.

- Recognition that notwithstanding some general commonalities, each watershed in the Great Lakes basin is unique, and planning initiatives must reflect and accommodate that uniqueness.

Chapter One

Science and the Great Lakes Water Quality Agreement

1.19 Summary

The Science Advisory Board held a workshop in February 2004 to review the Agreement from a scientific perspective. The fundamental question considered was whether the stated purpose of the Agreement is necessary and sufficient to meet present and future challenges. The workshop also focused on other themes related to the following questions:

- What is the present state of the science associated with the Agreement? Is the scientific knowledge implicit in the Agreement necessary and sufficient to achieve the Agreement's purpose?
- What new or additional scientific information is required?
- What new elements might be considered and what is the state of the science to support them?
- Can the existing Agreement accommodate present and future issues, including but not limited to alien invasive species, habitat, land use, climate change, biodiversity, pathogens, new chemicals, and long-range transport of atmospheric pollutants?
- Do current institutional arrangements under the Agreement help or hinder the application of science?
- Are current Great Lakes research institutions organized to deliver science in the 21st century?

The consensus among workshop participants was that scientific understanding has advanced far beyond current Agreement provisions. In order to update and strengthen the scientific basis for Great Lakes water resource management when the Parties revise the Agreement, comprehensive analysis and advice is provided below.

1.20 Workshop: Review of the Agreement from a Scientific Perspective

Following release of the International Joint Commission's 12th Biennial Report in 2004, the Parties are required to "conduct a comprehensive review of the operation and effectiveness of the Agreement." The IJC has committed to issue a special report providing advice to the Parties regarding the review and its role in the review. The IJC instructed its Boards and Council to explore the nature of the advice that they could provide. The lead was assigned to the WQB, with the SAB, International Air Quality Advisory Board, and the Council of Great Lakes Research Managers contributing in their areas of expertise.

The SAB is the scientific advisor to both the IJC and the WQB. To develop the requested advice, the SAB held a workshop to review the Great Lakes Water Quality Agreement from a scientific perspective. The approximately 50 attendees included SAB members, invited experts, IJC scientific staff, and the Canadian co-chair of the IJC.

The workshop was structured to:

- Review the adequacy of the Agreement to accommodate present and future stressors that impact Great Lakes water quality.

- Suggest specific areas of the Agreement where, from a scientific perspective, provisions might be added, revised, or deleted.

The fundamental question considered was whether the stated purpose of the Agreement is necessary and sufficient to meet present and future challenges. The workshop also focused on other themes related to the following questions:

- What is the present state of the science associated with the Agreement? Is the scientific knowledge implicit in the Agreement necessary and sufficient to achieve the Agreement's purpose? Why or why not?
- If not, what new or additional scientific information is required?
- What new elements might be considered and what is the state of the science to support them?
- Can the existing Agreement accommodate present and future issues, including but not limited to alien invasive species, habitat, land use, climate change, biodiversity, pathogens, new chemicals, and long-range transport of atmospheric pollutants?

The linkages between research, science, and policy were also examined:

- Do current institutional arrangements under the Agreement help or hinder the application of science?
- Are current Great Lakes research institutions organized to deliver science in the 21st century? If not, what organizational changes would be suggested?
- How can science-policy linkages be strengthened?
- How might the Parties undertake a detailed scientific review?

1.21 Discussion Highlights

The Agreement emphasizes control of persistent toxic substances within a wider context of restoration and enhancement of the boundary waters. From a scientific standpoint, the most significant provision with regard to the Agreement review is the statement that restoration and enhancement "cannot be achieved independently of other parts of the Great Lakes Basin Ecosystem with which these waters interact." Since 1987, ecosystem management has been approached through a variety of programs and initiatives pursued under the increasingly broad umbrella of the Agreement. Thus, any science-based review of the Agreement must address the fundamental and obvious questions: What is the intended scope of the Agreement? Should a primary emphasis continue to be on the control of persistent toxic substances? Is the restoration and maintenance of chemical, physical, and biological integrity of the waters of the Great Lakes basin ecosystem achievable under current science and policy approaches? Or, should ecosystem management be addressed more explicitly and a broader range of restoration and protection programs be officially sanctioned in the Agreement in order to fulfill its purpose?

This is as much a science question as a policy question. It could be argued that the Agreement evolved some time ago into an ecosystem approach for managing air, water, and land resources and associated uses. While water quality is still the predominant focus, the option of updating the Agreement to reflect actual practice merits serious consideration. If updated on this basis, a new title such as the "Great Lakes Ecosystem Agreement" would more accurately reflect an ecosystem focus. Additional provisions in the preamble could acknowledge that restoration and maintenance of the physical, chemical, and biological integrity are interdependent goals that fundamentally depend on the management of all ecosystem components.

> Is the restoration and maintenance of chemical, physical, and biological integrity of the waters of the Great Lakes basin ecosystem achievable under current science and policy approaches?

Since 1987, the science of restoration and protection has evolved considerably beyond the policies of pollution prevention and regulatory control. If the Agreement is to be revised to embrace a broad range of ecosystem management goals, consideration needs to be given to revising the statement of purpose accordingly to recognize the associated scientific requirements. For example, a statement could be included that calls for science-based plans and management practices within the context of an ecosystem approach, which is directed towards all ecosystem components and stressors.

With regard to the General Objectives, five very broad objectives relate to substances, materials, and nutrients that the Parties commit to keeping "free from" the Great Lakes system. These objectives could be expanded to include positive aspects that encompass desirable attributes as well as those that are to be avoided.

A new Agreement needs to be forward looking with the flexibility to accommodate ecosystem surprises and stressors that may not now be present but could emerge in the future. For example, a number of ecosystem stressors, such as invasive species, climate change, and new chemicals, were identified by the SAB through their expert consultation on emerging issues.

1.21.1 Process-Based Objectives

In any future Agreement, process-based rather than target-based objectives could be used. Process-based objectives can also encompass targets that change over time. The process itself could suffice in a future Agreement for two reasons: first, to incorporate a more integrated approach to the biological, physical, and chemical integrity of the Great Lakes; and second, when setting chemical objectives, the substances of concern in the future may be unknown today. However, by agreeing to a process that can identify them, they can be addressed according to the problem that they represent. For example, a review process could be implemented that incorporates all current objectives and accommodates differences through binational review if compliance of any numeric standard is exceeded.

Another example is climate change. The science related to climate change is well understood, and for the Great Lakes a process goal could be established to ascertain the effects of climate change on the Great Lakes by developing a credible regional atmospheric circulation model. The model could specifically incorporate the interactions of the lakes with the atmosphere and link to global, dynamic circulation models.

1.21.2 Remediation and Restoration

The purpose of the Agreement is to restore and maintain the integrity of the waters of the Great Lakes basin ecosystem. Annex 2 is central to that purpose in terms of binational planning efforts to support implementation and progress. Annex 2 defines 14 beneficial use impairments and outlines a method of integrating various planning processes to facilitate local and basinwide recovery. Scientifically, the broad knowledge and understanding upon which Great Lakes planning and decision making are based is enviable by world standards. However, there are challenges still to be addressed including:

- Strengthening indicator reporting as opposed to focusing on indicator development.
- The use of geographic information systems and models to produce predictive analysis.
- A scientific definition of restoration.
- More involvement of the research community in remedial activities.
- Strengthening scientific understanding of specific causes of use impairments.
- Establishing pre- and post-remedial monitoring programs to assess project effectiveness and progress.
- Recognizing an implementation stage based on the concept of an "area of recovery."
- Improved progress reporting.
- Increasing recognition that lakewide planning is a dynamic process, not linear and static as currently defined in the Agreement.
- Economic cost-benefit analysis that demonstrates feasibility, supports decision making, and sustains implementation efforts.

1.21.3 Surveillance, Monitoring, and Research

There is a strong consensus that more monitoring is needed. The application of specific scientific knowledge on critical issues, or the use of new knowledge to support policy initiatives and achieve greater progress, rarely occurs and illustrates the limited effectiveness of current programs.

Most scientific knowledge generated under Annex 11 exists on the basis of very few chemicals and for only a few subsystems of the Great Lakes. Because such knowledge has been developed under a research and not a monitoring paradigm, the knowledge base is incomplete. While assessment programs exist, they are narrowly focused and do not comprise an adequate basis for pollution-trend analysis that addresses scientific needs or capabilities.

Identifying emerging problems remains a weakness, not because of scientific limitations or capability but because Great Lakes management is reactive by nature. Managers and decision makers react to problems according to the dictates of the Agreement, and thus policy and programs are always "behind the curve" in the Great Lakes. Science can be predictive, but has been rarely used to avoid future problems in the Great Lakes. With insufficient regard for the future, there is a strong possibility that emerging problems may be overlooked.

In order to support Annex 2 activities, scientific data and actual management actions under the RAPs and LaMPs must be linked to adequate monitoring programs. Monitoring programs to support implementation, area of recovery designation, delisting, and restoration do not exist and are not identified in the current Agreement. For example, sampling designs have not been developed.

The State of the Lakes Ecosystem Conference (SOLEC) program and the SOLEC list of indicators are evidence of ongoing interest in indicators for the Great Lakes basin. However, from the long list of indicators proposed under SOLEC, very few have been validated. There is a general assumption that the indicators are supported by monitoring data and have been scientifically validated. Unfortunately this is not the case. Both data and scientific understanding are needed to validate the selected indicators. In turn, the indicators could support the development of indices that combine indicators into meaningful reporting frameworks. The relationship of monitoring and modeling needs to be integrated in order to understand the ecosystem as a whole. Similarly, better linkage between exposure and effects would improve management and decision making.

The Integrated Atmospheric Deposition Network comprises the only truly binational surveillance program and demonstrates the potential of effective binational programs. New scientific approaches to address monitoring for the open waters of the Great Lakes include technological opportunities available to establish observing systems similar to those that are used to study the oceans. As planning and implementation of the Great Lakes Observing System is considered, there are obvious benefits of securing its potential role as a binational commitment within a future Agreement.

Other scientific approaches also could be used to improve our ability to anticipate and predict future problems. Quantitative structure activity relationships can identify chemicals that will cause problems before they are released into the environment. Other predictive approaches could be applied to address issues such as microbial contaminants, exotic species, and critical populations.

An important scientific approach whose value was recognized about 50 years ago is validated mass balance models for all of the lakes. It was assumed that once one model was validated it could be applied to the rest of the lakes. To date, only one model for Lake Michigan has been produced in part and is still under development. The other lakes do not have validated mass-balance models, nor are any planned. This science needs to be applied to the whole basin, both in terms of the models' creation and the databases to validate them, because such approaches could facilitate preventive actions. Anticipating and preventing a problem would avoid costly reactionary responses such as the after-the-fact monitoring and remediation occurring throughout the Great Lakes basin.

1.21.4 Delivery of Science through the Agreement

Can the existing Agreement accommodate the range of present and future issues? The short answer is "yes." The language is flexible enough, for example, to allow for research, monitoring, and technology development or transfer. The annexes comprise the specific approaches that together implement an ecosystem approach.

Beyond the scientific aspects, the Agreement assigns responsibilities to the Parties and to the IJC. Fulfilling these responsibilities requires scientific information. The ability of the governments to obtain scientific information is limited, and there is a concern that broadening the Agreement to address issues of ecosystem management beyond the focus on water quality will diminish their capacity for specificity and progress. A broadening of the Agreement could create additional obligations and expectations that cannot be adequately funded.

Since political will and not science drives action, how should the Agreement be revised to achieve implementation? The answer lies in incorporating human health and well being and other societal issues under the annexes. This would make the Agreement more relevant to ordinary citizens, particularly if clear and readily understood language is used. If the tasks of reporting science, interpreting policy, and accounting for progress were diligently addressed, the political will could follow to support continued progress under the Agreement.

Are current research institutions organized to deliver science in the 21st century? While the institutions support scientific activities that in turn drive Agreement policies, the national and international scales of pollutant impacts are not adequately reflected in the Agreement. Historically, science and technology have always outpaced institutional innovation, and that is also evident in the Great Lakes region. The upcoming review provides a good opportunity for the institutional aspects to better reflect current scientific knowledge and technological innovations. An example is the development of a proposed Great Lakes Observing System, where the science and technology is readily available, yet there is no unified institution or binational arrangement to implement such a system for the Great Lakes.

Can science-policy linkages be strengthened? This question was framed in relation to the idea of a collective vision. If the Agreement is revised, there is always the risk that the current focus on water quality and the concern for the threat and injury to human health will be diminished. Ecosystem health has improved, yet we are so far away from our goal it might be a mistake to abandon it and adopt a new one. The issue of PCBs in Great Lakes fish demonstrates this point. PCBs are the primary risk for human and ecological health. Unless aggressive remedial action is taken on sediment cleanup, fish consumption advisories in Lake Michigan will be inevitable for the next 100 years. Based on the public's awareness of this issue, it is obvious that such consequences are poorly understood and communicated. For example, claiming success by stating that PCB levels have been reduced 10-fold is premature. The reality is that significant reductions from the current levels are needed to fully protect human health. Ultimately the removal of fish-consumption advisories will require significant actions, expenditures, and scientific management to achieve restoration goals.

In terms of persistent toxic substances, the questions are, "How do we get our focus back on these key priorities given the need for sustained action well into the future?" and "How does one balance long-term management issues with other priorities in the shorter term?"

While some progress has been made under the Agreement, only a fraction of what is in the annexes has been implemented. An element of caution is appropriate in assuming that additional commitments or strengthening the existing Agreement will result in greater implementation and progress.

1.22 Conclusions and Advice

1.22.1 Scientific Principles

Workshop participants concluded and advised the SAB that the following scientific principles be reflected in a revised Agreement.

<u>Principle 1</u>. Managing the Great Lakes needs to be broader than water quality. Scientific knowledge is not adequate at present to manage the basin as an ecosystem. Present scientific knowledge is sufficient for a broad integrated understanding of water quality problems involving the major ecological functions and the components of the watershed, the airshed, and groundwater.

<u>Principle 2</u>. A new Agreement must encompass numeric as well as process approaches in order to benefit from the latest scientific knowledge and information. Two complementary scientific approaches are currently being used: numerical based on objectives and process-oriented based on the most current understanding of the dynamic performance of the system. There are merits to the continued inclusion of both.

<u>Principle 3</u>. The interrelationship of water quality, ecosystem health, and water quantity is well established scientifically and should be recognized as such in a new Agreement. Examples of the interrelationship include tributary flow, groundwater recharge, and wetland dynamics in which the quality of the ecosystem is highly dependent on the amount of available water.

Principle 4. A binational scientific infrastructure to provide surveillance and monitoring information that supports policy and management must underpin any Agreement, and should be institutionalized as an essential component to link science and policy.

Principle 5. The Agreement must be consistent and integrated with numerous other transboundary instruments. Some of its challenges are continental, such as those addressed under the North American Free Trade Agreement by the Commission for Environmental Cooperation, and global, such as those addressed by the International Maritime Organization through the International Convention for the Control and Management of Ship's Ballast Water and Sediments. To ensure that Great Lakes policies are coherent and effective, the Agreement would benefit from establishing scientific linkages among other instruments such as those developed for the control of persistent toxic substances including the United Nations Economic Commission for Europe Convention on Long-range Transboundary Air Pollution and the United Nations Stockholm Convention on Persistent Organic Pollutants.

1.22.2 Overarching Conclusions and Advice

Workshop participants concluded and advised the SAB that the following general improvements be adopted as pertaining to the broad aspects of the Agreement.

- Agreement language needs to define the term "ecosystem approach" and also provide clear guidance on how that approach can be implemented to advance Agreement goals and objectives.

- "Integrity" needs a definition and a common scientific understanding. Restoring and maintaining integrity needs greater expression in order to provide a renewed purpose in a new Agreement.

- "Restoration" needs to be defined scientifically and understood as a goal and a vision to sustain progress and commitment to Great Lakes improvement. One suggestion is to define it in terms of achieving beneficial uses. Restoration of the Great Lakes to a pre-settlement benchmark is not realistic.

- The Agreement should specify responsibility for reporting, interpretation, and accountability. Who is responsible for progress and what is the schedule for reports and responses? The institutional arrangements required to support and implement the Agreement should be updated and their roles clarified, especially governance mechanisms that facilitate binational cooperation, coordination, and ecosystem management. The Agreement needs to require that the responses of the Parties to all IJC recommendations are provided in a timely, public, and substantive manner.

- The review process needs to be defined, strengthened and driven by scientific understanding. An independent binational scientific review of the Agreement should be conducted similar to the one that occurred in 1985 with the binational National Research Council / Royal Society of Canada report, *The Great Lakes Water Quality Agreement – An Evolving Instrument for Ecosystem Management*.

- The Agreement must be both proactive and reactive, especially regarding emerging issues such as alien invasive species, land use, habitat protection, biodiversity, and climate change. Flexibility is needed to accommodate new scientific information. This could be accomplished by explicitly incorporating a routine scientific assessment of emerging issues explicitly in a new Agreement.

- Public health should be explicitly addressed as a basin issue that is affected by water quality, air quality, and land use. It requires an integrated approach among all orders of government and a greatly enhanced awareness and sharing of information among health professionals and practitioners.

- The Agreement should reflect a methodology that determines risk and uses that determination in guiding binational priority setting and action to reduce risk. Understanding exposures as well as effects in the context of risk is needed. Risk assessment, management, and communication need to be encompassed within the broader policy context of the precautionary principle rather than a regulatory one that drives management decision-making.

- Several annexes could be combined to improve their general effectiveness, especially streamlined implementation and reporting. Examples include Annexes 4-6 with 8-10, Annex 3 with 13, and Annex 2 with 7 and 14.

1.22.3 Specific Conclusions and Advice

Workshop participants concluded and advised the SAB that the following specific revisions be applied to a revised Agreement.

Article I – Additional definitions are needed to clarify scientific meaning in the Agreement. These include general terms such as risk, airshed, restoration, integrity, and watershed, whose definitions could be context specific. Exemplar definitions are provided for current and prospective terms. These definitions complement those provided by the WQB in Chapter 1.15 above.

Ecosystem approach: A science and policy framework that recognizes the fundamental interconnections of all ecosystem components and emphasizes the maintenance of biological diversity, natural relationships among all species including humans, and dynamic processes that ensure ecosystem sustainability.

Aquatic nuisance species: Non-indigenous (non-native), water-dwelling plants, animals, or other viable biological materials that enter an ecosystem beyond their natural range, are harmful, and threaten the diversity or abundance of native species; the ecological stability of infested waters, wetlands, or other property; or the commercial, agricultural, aquacultural, or recreational activities dependent on such waters, including human health.

Native species: Those plant or animal species originally living, growing, or produced in an ecosystem within their historic range.

Biodiversity: The full range of variety and variability within and among living organisms and the natural associations in which they occur.

Ecosystem stressor: An agent of change in the physical, chemical and/or biological characteristics of the ecosystem, often the result of human activity that compromises ecosystem integrity.

Biodiversity Investment Area: A geographic area within the Great Lakes basin ecosystem that supports exceptionally rich biodiversity and/or endemism and contributes significantly to the integrity of the ecosystem. Such areas contain habitat that supports natural, self-sustaining productivity and long-term ecological integrity.

Habitat: The physical, chemical, and biological characteristics at a particular locality that collectively support an organism, population, or community, including the basic life requirements of food, water, substrate, and cover or shelter.

Stewardship: The careful and responsible management of ecosystem resources entrusted to humans in the interest of achieving and protecting ecosystem integrity for its intrinsic value and/or for the benefit of current and future generations.

Sustainable use: The consumption or employment of a resource which, all other factors being equal, does not cause depletion that harms the resource or constitutes a threat to ecosystem integrity for present and future generations.

Article II – Paragraph (c) needs to emphasize science-based planning and best management practices to ensure that an ecosystem approach is adopted by all orders of government with shared responsibilities for planning, particularly local governments with respect to land use. Because of their cumulative impacts, isolated land-use decisions need to be integrated at the basin level to determine the desirable and appropriate level of development that can be sustained while at the same time protecting the integrity of the Great Lakes for future generations.

Article III – General objectives need to be expressed positively and speak to a vision of the Great Lakes that can be acted upon to achieve progress.

Article IV and Annex 1 are linked. The topic was evaluated by the SAB at the Review of Annex 1 of the Great Lakes Water Quality Agreement workshop held in Ann Arbor, Michigan on March 21, 2001. The recommendations contained in the 1999-2001 Priorities Report are still valid.

Articles V and VI – Not the subject of discussion at the workshop.

Articles VII – XV – No specific revisions were identified.

Annex 2 – Binational priorities need to be set and remediation based on scientific rationale at the Area of Concern and LaMP level.

Specify linkage to Annex 14 or combine with Annexes 7 and 14.

Improve implementation and linkage to applied science, particularly sampling and monitoring.

Provide consistent binational delisting criteria that are scientifically based and provide flexibility to accommodate local needs.

Annex 3 – The scientific appropriateness of the target loads should be reaffirmed. Phosphorus management needs to be revitalized using watershed planning, urban nonpoint and storm water management, and land-use best management practices. The science to support these efforts is mature.

Annexes 4-6 and 8-10 – A combined annex should be developed that includes a standard to protect the Great Lakes from international ships discharging ballast. These annexes can be combined since the regulatory regime to support them is mature, the programs of both countries are closely coordinated, and cooperation among responsible agencies is excellent. What is required is a discharge standard for ballast water that is based on current scientific knowledge. The standard should be expressed as a concentration that limits the number of organisms per volume of ballast water discharged to achieve the goal of no new introductions of alien invasive species. Such a ballast-water discharge standard must be scientifically sound, environmentally protective, and enforceable, and contain provisions for regular review and updating in light of new threats and technological capabilities.

Annexes 7 and 14 need to be combined and directly linked to Annex 2 or included as a subsection of Annex 2 in order to strengthen remedial action and restoration of beneficial uses as the goal of all sediment-management activities in the Great Lakes. The scientific approach to be adopted must be:

Based on risk assessment and risk management in terms of both human and ecological health.

Quantifiable, in terms of remedial technologies, particularly where alternative and combination technologies (*e.g.*, natural recovery) are proposed.

Demonstrable in terms of effectiveness by including post-project monitoring throughout the planned-recovery schedule.

Annex 11 – Renewal is required to support implementation of a systematic, science-based program that has data-quality objectives and data-collection plans that are driven by models of ecosystem behavior and contaminant fate.

Develop binational surveillance programs for water quality management similar to the Integrated Atmospheric Deposition Network (IADN).

Incorporate research elements into monitoring programs in a coherent fashion. Any surveillance program must be designed in the context of current models and data-collection techniques, such as the Global Earth Observation System of Systems and the Great Lakes Observing System now under development. Some envisioned elements include:

- Remote sensing and geographic information system-based technologies;
- Biomarkers and bioindicators;
- Indices that combine validated indictors in a meaningful way; and
- Satellite-linked observation buoys/systems.

Develop tools such as quantitative structure activity relationships to anticipate contaminant problems for new chemicals before they occur. Similar approaches are being developed for microbial contaminants.

Develop integrated, consistent, and effective data management/ informatics capacity.

Annex 12 should include a greater emphasis on public-health impacts resulting from changing exposures and include an institutional arrangement to enhance binational cooperation and coordination of human health research and monitoring of critical Great Lakes populations. While concentrations of many chemicals are declining, additional human-health hazards result from low exposures and mixture effects.

Annex 15 should be revised to incorporate advancements in meteorology, chemistry, and mathematical modeling to improve estimates of the nature and extent of impact of local, regional, and global emission sources on the basin. The Parties have been responsive to many aspects of the current annex, particularly in the establishment of IADN. However, this improved integrative approach to science should be used to better quantify the contribution of sources within and outside the basin, including the Great Lakes basin itself, as a source of deposition in other locales such as the Arctic.

Annex 16 needs to better reflect the linkage between groundwater quantity and quality, water supply, and instream conditions. The annex's title and provisions need to reflect the broader pollution-prevention focus inherent in current source-water protection policies and programs in both countries.

Large-scale groundwater assessments should be undertaken beyond those indicated in Annex 16.

Annex 17 – A research strategy or framework should be developed with flexibility to address new and emerging questions of concern as well as current research questions. Any research strategy developed in response to new and emerging questions of concern should be linked to the fundamental scientific principles and purpose of the Agreement.

1.22.4 Traditional Ecological Knowledge

While not discussed specifically during the workshop, a further opportunity to enhance scientific knowledge and understanding of Great Lakes ecosystems was identified by the SAB during preparation of this report. The term "traditional ecological knowledge" refers to the important historic and anthropological understanding that aboriginal people possess based on their collective experience of living in the Great Lakes basin over thousands of years. Such knowledge offers a unique perspective in understanding changes that have occurred to the basin's ecosystem since European settlement. Such a perspective is valuable in order to establish goals that achieve restoration.

In addressing this topic in its 1997-1999 Priorities Report, the SAB recommended that:

- **The IJC advise the Parties of the importance of traditional ecological knowledge for understanding the Great Lakes basin ecosystem, and the need to develop mechanisms and processes to ensure that the opportunity to contribute such knowledge is fully provided to aboriginal people and their structures of governance.**

The SAB reiterates this recommendation and urges the Parties to build on the capacity of Western scientific approaches by incorporating traditional ecological knowledge under a revised Agreement. The SAB notes that traditional ecological knowledge has particular relevance to restoration activities and ecosystem management goals in relation to sustainability. For example, Akwesasne residents have been congratulated for terminating consumption of local fish, but these residents do not agree that changing traditional cultural practices is a solution to an environmentally contaminated food supply.

Strengthening a Science-Based Approach to Great Lakes Water Management through Institutional Arrangements and Governance: An Interim Report

1.23 Summary

The relevance of institutional arrangements and governance to binational water management in sustaining a science-based approach has been the hallmark of Commission involvement and progress under the Agreement since its adoption in 1972. The use of science is fundamental to wise management decisionmaking and effective use of resources to sustain progress towards Great Lakes restoration and protection.

To determine how institutional arrangements and governance structures can facilitate and support a broad, science-based approach, several issues were identified as central to understanding the challenge of developing new arrangements. Management approaches to large-scale international ecosystems or transboundary river systems vary widely, but nine core characteristics common to the most successful management regimes were identified:

(1) A high level of interagency, intergovernmental, and public-private information pooling;
(2) Integrated databases, common monitoring protocols, and joint ecosystem modeling;
(3) A central coordinating body;
(4) A set of functionally defined committees, subcommittees, or work groups;
(5) Centralized staff support;
(6) A coordinated program of communications, public education, and outreach;
(7) Nested scales of governance;
(8) Specific goals and timetables at all levels; and
(9) Genuine integration across issue areas and mission-specific agency responsibilities.

> ... the institutional arrangements required to support and implement the Agreement should be updated and their roles clarified, especially governance mechanisms that facilitate binational cooperation, coordination, and ecosystem management.

1.24 Introduction

The importance of institutional arrangements and governance to support binational water management of the Great Lakes under the Great Lakes Water Quality Agreement was initially recognized during the Expert Consultation on Emerging Issues held at Wingspread February 5-7, 2003. The Science Advisory Board (SAB) recommended 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." It was also evident from this consultation that science continues to be essential in order to address future challenges and achieve progress in the 21st century on Great Lakes water management.

As described in Section 1.22.2 of this chapter, the SAB concluded at its workshop in February 2004 "the institutional arrangements required to support and implement the Agreement should be updated and their roles clarified, especially governance mechanisms that facilitate binational cooperation, coordination, and ecosystem management." The relevance of institutional arrangements and governance to binational water management in sustaining a science-based approach has been the hallmark of IJC involvement and progress under the Agreement since its adoption in 1972. The use of science is fundamental to wise management decisionmaking and effective resource use to sustain progress towards Great Lakes restoration and protection. To determine how science can be strengthened by enhancing institutional arrangements and governance, the SAB's Work Group on Emerging Issues developed a work plan that extends into the 2005-2007 biennial cycle. The plan encompasses a three-step process:

(1) Analysis and development of expert discussion papers to better understand existing arrangements, challenges and opportunities.
(2) Assessment of public input to the work group at the Institutional Arrangements and Governance Session held at the IJC's 2005 Biennial Meeting in Kingston, Ontario.
(3) Hosting an expert consultation in January 2006 to develop findings and recommendations that address the scientific principles and overarching conclusions previously identified by the SAB.

Since these activities were not concluded within the 2003-2005 biennial cycle, this is an interim report of the work planned and completed to date. Preliminary findings are presented; final recommendations will be provided after conclusion of step 3, the expert consultation.

1.25 Framework for Expert Analysis

In addition to determining those institutional arrangements and governance structures that facilitate a broad, science-based approach, the work group identified six specific issues that are important to the challenge of developing new arrangements:

- Identifying the key elements that contribute to the success of existing binational initiatives.
- Assessing the need for and role of a central coordinating body to implement Agreement commitments.
- Determining the role of local governments in the governance structure, and in particular the ten largest urban communities as defined by the IJC in its 12th Biennial Report.
- Determining whether special mechanisms are needed to promote public health as an explicit goal under the Agreement, particularly the avoidance of injury from transboundary-polluting substances.
- Developing institutional arrangements to provide for shared management of surveillance and monitoring systems, *e.g.*, the development of an integrated Great Lakes Observing System.
- Identifying innovative or unique international approaches that have been adopted and proven successful for other transboundary commissions with similar goals of shared management of water resources.

To address these issues, discussion papers were invited from five experts on international environmental regimes: Dr. George Francis, University of Waterloo (Ontario); Dr. Brad Karkkainen, University of Minnesota; Dr. Stephen McCaffrey, University of the Pacific-McGeorge School of Law (California); Dr. Mark Sproule-Jones, McMaster University (Ontario); and Dr. Konrad von Moltke, Fellow, International Institute for Sustainable Development (Winnipeg). The following is a synthesis of their findings; observations and recommendations are theirs, not of the work group or the SAB.

1.26 The Experts' Analysis

1.26.1 Key Elements of Successful Binational Initiatives

It is necessary to understand the key elements that contribute to successful binational initiatives. Science is the foundation on which all environmental policy rests. Therefore, all international environmental regimes require a science-assessment foundation, that is high-quality scientific results characterized by jointly managed and integrated databases, common monitoring protocols, and joint exercises in ecosystem modeling (Von Moltke, McCaffrey, Karkkainen). One of the unique attributes of the current Agreement is the establishment of a Science Advisory Board as a binational institution (McCaffrey).

The success of existing binational initiatives for Great Lakes governance has largely depended on an organizational structure of decentralized cross-border policy networks associated with various uses of the lakes, and which include a diverse range of government, civil society/academic, and private actors as stakeholders (Francis, Karkkainen, Sproule-Jones). Over the past 30 years, management efficiency has been improved through binational and federal-state/provincial intergovernmental agreements that have fostered coordination and collaboration across sectoral and jurisdictional boundaries, and have reduced conflict among resource user groups (Francis, Sproule-Jones, Karkkainen). This overarching legal and organizational structure is supplemented by a large regional constituency of nongovernment, organization-based stewardship networks. The commitment of individuals in these networks to restore and protect their local watersheds is one of the strongest facets of the Great Lakes governance regime; in fact, it is the "glue" holding the components of the regime together (Francis, Sproule-Jones, von Moltke, Karkkainen, McCaffrey).

1.26.2 A Central Coordinating Body for Agreement Commitments

Assessment of the need for, and the role of a central coordinating body to implement Agreement commitments is necessary. Although decentralized policy networks have been responsible for successful binational ecosystem restoration initiatives, the informal and *ad hoc* nature of many efforts may also undermine the efficiency and effectiveness of the regime as a whole (Karkkainen, Sproule-Jones, von Moltke). A central coordinating body could formalize intergovernmental and multi-sectoral coordination and cooperation as well as integrate science and local knowledge into policy frameworks (Karkkainen). Data integration (*i.e.*, integrated databases, common monitoring protocols, and cooperative ecosystem modeling) to a central information hub would be highly beneficial, making the data easily accessible to policymakers and the public. This would help to articulate basinwide program goals and priorities

as well as foster consensus developed through collaborative networking (Karkkainen). Instituting a central coordinating authority may help provide strong signals at the basinwide level as to how planners, resource managers, and nongovernmental organization-led coalitions might more effectively link their efforts to achievement of basinwide goals. The notion of a central coordinating authority is distinct from an authoritative hierarchical institution in that its role at the "centre" would be one of redistributing information across units, providing a coordinating role to see that the parts cohere into some unified whole, and assessing progress systemwide.

1.26.3 The Role of Local Governments in Governance

The role of local governments in the governance structure is necessary, in particular, the ten largest urban communities as defined by the IJC in its 12th Biennial Report. Constitutional rules of both countries largely define local government as political subdivisions of the states or "creatures" of the provinces. In practice, local governments (particularly governments of the basin's largest cities) have considerable financial autonomy, land-use planning authority, and responsibility for environmental infrastructure that should be recognized by the Parties in the Agreement (Sproule-Jones, Francis). Initiatives exemplified by remedial action plans and other sub-basin land and water programs should mesh with Great Lakes basinwide programs administered by federal and state/provincial agencies (Francis). Recent initiatives by Great Lakes mayors have raised the profile of cities in the Great Lakes governance regime and have forged quasi-formal connections across the boundary with other local governments and connections to other tiers of government domestically. Institutional arrangements under a revised Agreement should represent the contributions and decisionmaking authority of local governments in matters related to water quality. The representation of local governments, such as in the Great Lakes Regional Collaboration process, is a positive development in the governance regime and should be interpreted as a signal that local governments expect to play an active role in the development of future Great Lakes policies and programs. Currently, the informal linkages among the representatives of the four orders of government (national, state/provincial, local, aboriginal), resource users, and regulators do not appear successful in building incentives across multiple users for aggregating or balancing interests (Sproule-Jones).

1.26.4 Special Mechanisms to Promote Public Health

Consideration must be given to whether special mechanisms are needed to promote public health as an explicit goal under the Agreement, in particular the avoidance of injury from transboundary-polluting substances. The promotion of public health, particularly within the context of Annex 2 activities, is a possible concern for the regime (Sproule-Jones). As a result of more research by the Parties, scientific understanding of health effects and injuries to public health from exposure to persistent toxic substances in the Great Lakes region increased throughout the 1990s. The challenge remains as to the appropriate policy response, and whether new institutional mechanisms are required to sustain protection of human health as a basin priority under the Agreement. In order to respond more definitively to this concern, the health advisors serving under the various boards, council, and Health Professionals Task Force have constituted a joint health-experts advisory group to assist the IJC in this aspect of the Agreement's review.

1.26.5 Institutional Arrangements for Shared Surveillance and Monitoring

Institutional arrangements must be considered for provision of shared management of surveillance and monitoring systems, that is, the development of an integrated Great Lakes Observing System. There are serious organizational deficiencies in the assessment and communication of science-based management options across scales of governance (Francis, Karkkainen, von Moltke, Sproule-Jones, McCaffrey). Binational institutional arrangements such as the IJC's SAB and science review conferences do not provide systematic assessment of the available science, nor do they have the ability to generate additional science to fill holes in the knowledge base (von Moltke). To ensure the delivery of science-based policymaking, the formation of an institution for independent Great Lakes science assessment is recommended (von Moltke, McCaffrey). As an alternative or supplement to this recommendation, Great Lakes regional science assessment should be considered part of the greater whole of global science assessment, such as the United Nations-initiated Millennium Ecosystem Assessment, the Intergovernmental Panel on Climate Change, and the Global Earth Observation System of Systems (von Moltke). Integrating regional science assessment institutions into corresponding global institutions would stimulate policy integration and coordinated actions that domestic assessments have been unable to create (von Moltke).

The most successful ecosystem management initiatives devote a good deal of effort to building a common, comprehensive, scientifically informed knowledge base to which all participants have full access, from which all participants work, and to which all are expected to contribute (Karkkainen). A binational Great Lakes Observing System should incorporate these characteristics and link scientific findings and monitoring data into processes or forums of independent science assessment.

1.26.6 International Approaches of Successful Transboundary Commissions

Innovative or unique international approaches adopted and proven successful in other transboundary commissions with similar goals of shared management of water resources must be considered. Management approaches to large-scale international ecosystems or transboundary river systems vary widely, yet more successful management regimes share certain characteristics. Citing the Chesapeake Bay Program, the Helsinki Commission (Baltic Sea basin), the European Union Water Framework Directive, and the CALFED San Francisco Bay-Delta initiative, nine core characteristics common to the most successful programs were identified:

(1) A high level of interagency, intergovernmental and public-private information pooling;
(2) Integrated databases, common monitoring protocols and joint ecosystem modeling;
(3) A central coordinating body;
(4) A set of functionally defined committees, subcommittees or work groups;
(5) Central staff support;
(6) A coordinated program of communications, public education and outreach;
(7) Nested scales of governance;
(8) Specific goals and timetables at all levels; and
(9) Genuine integration across issue areas and mission-specific agency responsibilities (Karkkainen).

Institutional mechanisms to improve public participation in the Great Lakes governance regime was also emphasized (McCaffrey, Sproule-Jones, Karkkainen, Francis). Democratizing features of the North American Commission for Environmental Cooperation (CEC) have been successful in facilitating public participation and encouraging compliance by the United States, Canada, and Mexico with their treaty obligations. The IJC, like the CEC, should be authorized to receive "citizen submissions" (claims that the Parties are failing to follow up on IJC recommendations or abide by Agreement terms) and set up a Public Advisory Committee under the Agreement (McCaffrey).

1.27 Next Steps, Preliminary Findings, and Questions for a Future Activity

In order to develop advice and recommendations for IJC consideration, assist the public review process at the 2005 Biennial Meeting, and provide an interim report to the IJC, the work group drew upon the insight provided to date and compiled a series of questions and statements to facilitate the expert-consultation phase of the project.

1.27.1 A Central Coordinating Body for Agreement Commitments

For a schematic node-and-network (Francis presentation) structure approach to governance that would provide the maximum opportunity for local control and minimize the need for a centralized control system:

- What are appropriate scales of governance nationally and internationally and how would these be reflected in any new Agreement?
- What gaps exist?
- Should the SAB try to assemble a proposed node-and-network structure for Great Lakes governance?
- What institutional arrangements would be most effective for science-based management of the Great Lakes – networked, centralized, shared, hierarchical, and/or flat?

1.27.2 The Role of Local Governments in Governance

For the concept of institutional "fit" and "problem structure" in the Great Lakes:

- What is the appropriate fit between problem structure and institutional structure that should be addressed in any new Agreement?
- What are appropriate mechanisms by which local governments are empowered to bring about restoration on appropriate scales?
- How is growth of urban centers most effectively and most beneficially managed for ecosystem and human health?

1.27.3 Institutional Arrangements for Shared Surveillance and Monitoring

The most far-reaching advice provided by the experts dealt with the formation of a binational science assessment body, a joint observation and monitoring network, and a "peak" coordinating body. Formation of such new institutions would require major, sustained investments.

- Would creation of a science assessment "body" add value to governance of the lakes?
- Are the three above-noted institutions needed?
- Would they promote and advance Great Lakes restoration based on science?
- Would the benefits of creating and sustaining these institutions outweigh the costs?
- How would these institutions be financed? Who should pay for them?
- How do we maximize the use of science to inform decisions for the Great Lakes?
- Does science-based decisionmaking favor one structure(s) over others?

1.27.4 International Approaches of Successful Transboundary Commissions

From the elements for successful governance, based on analysis of other approaches:

- How can the Great Lakes community best address the gaps or deficiencies identified for each of these elements?
- Which of these are priorities?
- How will the Parties and the IJC develop a common understanding of problems and a basis for a common goal(s) for all institutions in the Great Lakes?
- How will the new Agreement encompass adaptive management approaches associated with the evolving understanding of the challenges and pressures on the basin ecosystem?
- How could an overall "peak" coordinating body be organized and empowered to advance Great Lakes restoration through the various scales of governance?

REPORT OF THE COUNCIL OF GREAT LAKES RESEARCH MANAGERS

Defining a Research Coordination Strategy for the Great Lakes

1.28 Great Lakes Research Coordination Strategy Workshop

As part of its contribution to the review of the Great Lakes Water Quality Agreement, and in particular the ability of research to identify and address key scientific questions that inform management and policy decisions, the Council of Great Lakes Research Managers convened the Great Lakes Research Coordination Strategy workshop at the U.S. Environmental Protection Agency's (EPA) Great Lakes National Program Office (GLNPO) in Chicago on April 28-30, 2004. There were 33 attendees representing both U.S. and Canadian organizations throughout the Great Lakes basin, including 14 members of the Council.

The need for improving overall coordination of Great Lakes, coastal, and ocean activities has been emphasized repeatedly in recent years in reports from the International Joint Commission, the U.S. Government Accountability Office, the Canadian Auditor General, the Pew Oceans Commission, and the U.S. Commission on Ocean Policy. The Council chose this issue as a priority for 2003-2005 because it recognized the opportunity for the two governments to address improved research coordination during the upcoming Agreement review.

The workshop's purpose was to address the need for a binational Great Lakes research coordination strategy. This was defined as an overarching framework for Great Lakes research management and a mechanism for international cooperation by describing how the region will collaborate, organize, and coordinate large-scale research projects. The workshop provided a basis for Council advice and recommendations to the IJC.

The workshop was organized in two sessions. The first day-and-a-half public session consisted of U.S. and Canadian perspectives on regional coordination with presentations about lessons learned from regional or problem-driven coordination efforts, lakewide coordination efforts, and collaborative approaches. During the two half-day sessions that followed, the Council and other advisors met to identify elements of the research strategy and how to move the initiative forward.

1.29 Findings

As goals, the strategy should promote effective collaboration, avoid duplication, apply a holistic ecosystem approach, and effectively communicate science with a consistent message throughout the basin. The strategy will promote and facilitate collaborative research proposals and provide for an informed research-funding process that can address all categories of research in a strategic, effective, and flexible manner.

An effective research strategy should include the following attributes:

- Guiding principles;
- Clearly defined terms, roles, and processes, including a list of cooperating agencies and organizational chart(s);
- A key coordinating body with a clearly defined role; and
- A communications plan regarding how agencies will communicate their plans to all participating agencies and how urgent issues/needs will be communicated to the public and decisionmakers.

The plan should address requirements for effectively carrying out both long-term projects and short-term thematic or problem-driven research involving rapid response and pooling of resources. It should take advantage of existing organizations and avoid reinventing elements that are working well. It should also set research priorities and provide basic principles, structure, and mechanics for how priorities are looked at and set.

The need for improving overall coordination of Great Lakes, coastal, and ocean activities has been emphasized repeatedly in recent years ...

Three sources of research should be addressed:

- Management-driven research (focused on recognized needs)
- Thematic issues (not yet recognized by managers)
- Emerging issues (surprises).

The workshop participants used a process employed by the Lake Erie Millennium Network (LEMN) to identify specific activities that should be incorporated in the research coordination strategy. The LEMN process addresses eight process questions regarding the origin and fate of research ideas to be pursued in the Great Lakes basin:

1. Where will the ideas come from?
2. Where will the issues come from?
3. Who will synthesize the ideas into a theme?
4. Who will promote the theme?
5. Who will advertise the theme and get participants?
6. Who will organize the logistics of the theme?
7. Who will coordinate the resources?
8. Who will coordinate the reporting and the databases?

1.29.1 Where will the ideas come from?

Three sources of research typically drive activity. Management-driven research ideas come from well-recognized needs such as fisheries management and lamprey control. Thematic research ideas come from issues such as chemicals, pathogens, invasive species, habitat loss, and anthropogenic effects that are not fully understood. Emerging issues are surprises, such as unexpected bird and fish kills that must be studied in order to answer public concerns and to inform management decisions. Recommendations from participants included:

- Consult with science advisory groups (expert consultations);
- Develop a stable funding source for Great Lakes research workshops;
- Coordinate with existing workshops/conferences such as those sponsored by the International Association for Great Lakes Research;
- Sponsor new research-oriented thematic workshops; and
- Use the Internet to gather input from "cyber seminars."

1.29.2 Where will the issues come from?

An effective communications plan would ensure rapid and effective communication at all levels. Researchers in touch with what is happening in the field need to be assured that new ideas will receive the attention and full consideration of decisionmakers. It was recommended that the strategy include developing a well-known forum where people know their idea will be discussed through the entire Great Lakes community.

1.29.3 Who will synthesize the ideas into a theme?

The outcome of the workshops, cyber seminars, and teleconferences would be a recommended research theme for funding consideration.

1.29.4 Who will promote the theme?

Participants suggested this as a possible role for the Council, as well as facilitating peer review, media events, and other public promotions.

1.29.5 Who will advertise the theme and get participants?

It was recommended that the Council serve as a clearinghouse where Requests for Proposals (RFPs) from agencies could be easily accessed and publicized using the Council website. The Council's list server could advertise when and how RFPs would be released, along with early pre-award planning information. To gain broad support, partnerships would be formed with existing research consortiums, academic institutions, the Great Lakes Commission, the Council of Great Lakes Governors, individual government agencies, and nongovernmental organizations.

1.29.6 Who will organize the logistics of the theme?

Recommendations included contracting with experts from the scientific community, designating a separate coordinating entity at a partnering agency to receive funding, and partnering with private industry and equipment suppliers. It was also suggested that existing agency logistics personnel and database managers be utilized as much as possible, with well-defined work plans, timelines, and funding.

1.29.7 Who will coordinate the resources?

Recommendations for resource coordination included the Council as a workshop sponsor, forming a committee to coordinate Great Lakes resources, and a coalition of agency leaders. It was suggested that the Council consider the National Oceanographic Partnership Program as an interagency model (www.nopp.org).

1.29.8 Who will coordinate the reporting and the databases?

It was recommended that a portal for data housed at agencies be provided and that the strategy align with the data-management plan for the Great Lakes Observing System. In addition, it was recommended that the Council or a reformulated research coordination council be established where issues and themes (*e.g.*, from a workshop) could be reported. The coordinating body would discuss the pros and cons of the workshop recommendations, obtain a consensus, and identify agencies that wish to contribute, as well as funding sources. The result would be a truly coordinated research project of substantial scale.

1.30 Future Plans

The Council will incorporate the attributes described above into a draft research coordination strategy. Further collaboration with the Great Lakes Fishery Commission to finalize and implement the strategy will be explored. Workshops and further meetings will be organized to gather input on the draft strategy and examine how efforts should mesh with those of the Great Lakes Regional Collaboration, and a test-case project will be carried out during the upcoming year.

1.31 Recommendation

Rather than providing a "laundry list" of research topics as currently found in Annex 17, potential revisions to the Agreement should mandate a process aimed at identifying and addressing key scientific questions as well as informing management and policy decisions. To maximize collaboration and effective use of resources, a clearly identified coordinating body should also be designated in the Agreement with a responsibility to provide an open forum for communication among scientists and granting agencies.

The Council recommends to the IJC that:

- **The Parties incorporate a research coordination process involving the Council of Great Lakes Research Managers into a revised Agreement.**

ATMOSPHERIC TRANSPORT OF MERCURY

THE COMMISSION'S PRIORITY

Modelling the sources and pathways of mercury from the atmosphere to receiving waters of the Great Lakes continues from prior biennial cycles, and will extend beyond the current 2003-2005 cycle. Scenarios for abatement of mercury for various emissions are being examined and recommendations for policy consideration will be made.

Chapter Two presents advice and insight from the International Air Quality Advisory Board to the Commission regarding atmospheric transport of mercury and the uptake of mercury by denizens of the Great Lakes basin.

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Chapter Two

ATMOSPHERIC TRANSPORT OF MERCURY

REPORT OF THE INTERNATIONAL AIR QUALITY ADVISORY BOARD

Development of a Multi-Compartment Mercury Model for Lake Ontario: Tracking Mercury from Sources, Deposition, and Dispersion to Fish and Accumulation in Humans

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Development of a Multi-Compartment Mercury Model for Lake Ontario: Tracking Mercury from Sources, Deposition, and Dispersion to Fish and Accumulation in Humans

2.1 Introduction

Sediments and fish in the Great Lakes have been contaminated by mercury for an extensive period. High levels of mercury in sport and commercial fish species are the result of accumulated and continually augmented supplies. Mercury has been and is a prevalent factor in the lakes' fish consumption advisories, a topic discussed in several previous Board priority reports and International Joint Commission Biennial Reports. The ultimate consequence for humans whose diet includes regular consumption of contaminated fish is an accumulation of mercury; the extent of such accumulation and related reference-dose information are discussed by the Science Advisory Board (SAB) in Chapter Five of this report.

Since 1995, in partial fulfillment of Annex 15 (Atmospheric Deposition) of the Great Lakes Water Quality Agreement, the International Air Quality Advisory Board (IAQAB) has supported the application of the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) atmospheric transport and deposition model to estimate the extent to which selected persistent toxic substances, including dioxin and mercury, enter the Great Lakes via the air pathway. This work has been directed by the National Oceanic and Atmospheric Administration's (NOAA) Air Resources Laboratory, with continual substantial support from the U.S. Environmental Protection Agency (EPA) and assistance from Environment Canada and other agencies.

Initial investigations focused on dioxin, and results were reported in the 1995-1997 and 1997-1999 Priority Reports. The 1999-2001 Priority Report provided an overview of various factors and issues involved in such modeling efforts.

In 2001, noting the continued prevalence of fish advisories resulting from the presence of mercury in the Great Lakes basin and elsewhere, and the dominance of atmospheric deposition as a pathway for this pollutant to waterbodies, the IAQAB supported efforts to model transport and deposition of this contaminant. The HYSPLIT model was applied to estimate mercury's transport and deposition to the Great Lakes basin and individual lakes therein, and reported on in the *2001-2003 Priorities Report*. The rationale for this initial work and related findings, conclusions, and recommendations are noted below; however, those seeking to grasp the full scope of the IAQAB mercury effort are encouraged to refer to the 2001-2003 report. The effects of mercury on human health are also outlined in that document and the IJC's Twelfth Biennial Report provides additional information on mercury sources and deposition. Both are available at the IJC's website (www.ijc.org) and should be consulted for a comprehensive understanding of this issue.

In the course of this work, the need for information to inform and support policy development regarding the potential effectiveness of proposed emissions reductions was evident, including their impact on concentrations of methylmercury (MeHg) in fish and resulting human exposure. However, the movement of mercury through the environment is complex, and crucial relationships that can quantify the exposure pathway are still scientifically uncertain. Uncertainties regarding environmental factors controlling chemical transformations between inorganic mercury and MeHg, and the vector of mercury entry into the base of the food chain, make it difficult to establish linkages among emissions sources, ambient concentrations, and human exposure. No mechanistic model exists that can forecast the impact of potential emissions changes on mercury concentrations in fish without extensive calibration data from the study site in question (Mason *et al.* 2005). The scientific limitations of current mechanistic models are discussed in greater detail below.

In 2001, noting the continued prevalence of fish advisories resulting from the presence of mercury in the Great Lakes basin and elsewhere, and the dominance of atmospheric deposition as a pathway for this pollutant to waterbodies, the IAQAB supported efforts to model transport and deposition of this contaminant.

Following completion of the first iteration of the HYSPLIT model application to estimate mercury transport and deposition to the Great Lakes, the IAQAB and scientists in the U.S. EPA, NOAA, Environment Canada, and other agencies agreed to further model the behaviour of mercury in the ecosystem. This project analyzes the movement and transformation of mercury from various sources in various media (emissions, effluent, and runoff) to a particular waterbody (Lake Ontario in this instance), tracks its cycling and fate in the waterbody, and follows the small fraction that bioaccumulates in the food chain and results in human exposure through consumption of contaminated fish. The risks associated with consumption can then be estimated.

Once the ability to track mercury to this extent has been demonstrated, a tool will be developed that allows policymakers and others to track and distinguish among mercury inputs from various natural and anthropogenic sources and source segments. The tool will also forecast the outcome of various mercury reduction proposals and programs on mercury levels in fish and ultimately on human exposure, as well as estimating the associated time required for such reductions to be reflected in sport and subsistence fish species.

In this interim description of the work to create this complex interactive model, the IAQAB reviews the most salient factors influencing mercury contamination in the Great Lakes, the most recent findings from transport and deposition modeling, and modeling mechanisms that might link mercury emissions to mercury presence in fish and humans. The bibliography in Chapter 2.5 presents literature references from which the reader can obtain additional details.

2.2 Reviewing the Individual Components: Deposition; Dispersion in the Water Column, Sediment, and Biota; and Uptake by Humans

2.2.1 Atmospheric Mercury Transport and Deposition

Introduction

In recent decades, the dominant mercury pathway to the Great Lakes has shifted from direct effluent discharges to the water to deposition of various mercury forms from the atmosphere to the lakes and adjacent watershed. This process is bidirectional in that a significant amount of mercury, particularly in summer months, evaporates into the atmosphere from the lakes.

Several human activities result in the release of mercury into the atmosphere, including metallurgical processing, municipal and medical waste incineration, and electrical power generation, particularly that associated with coal combustion. Mercury is also released to the atmosphere by various natural phenomena, including volcanic eruptions, forest fires, and the weathering of geological formations. An overall estimate of the magnitude of anthropogenic and natural emissions is given in Figure 1.

Mercury in the atmosphere occurs principally in three different chemical forms, or species: elemental mercury; reactive gaseous mercury; and mercury associated with or captured within

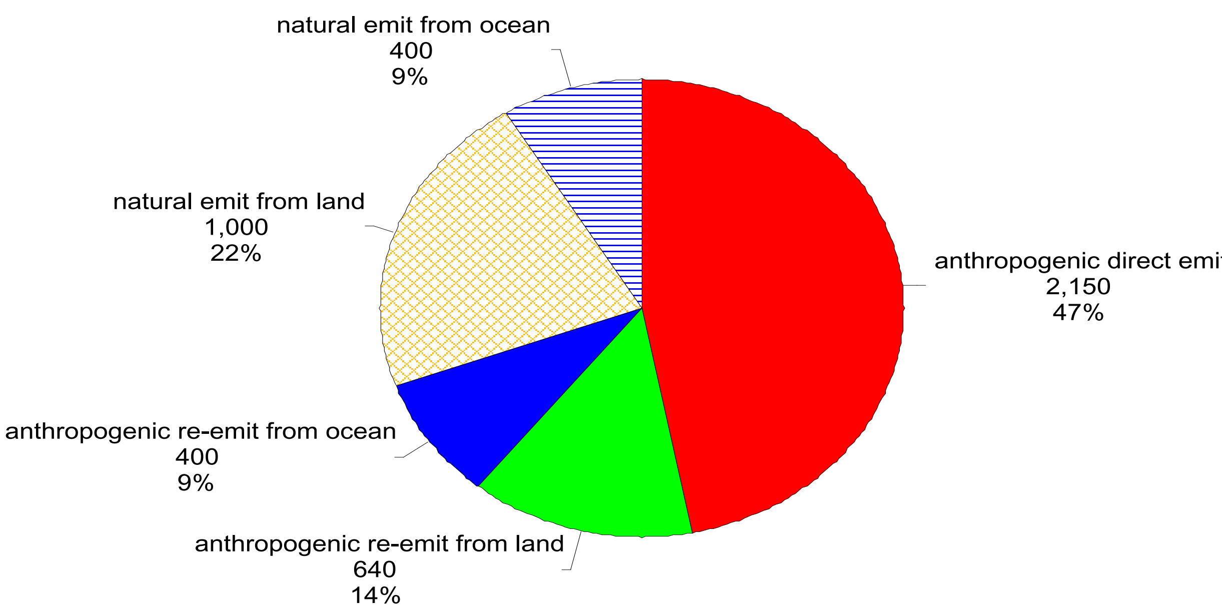


Figure 1. Global Natural and Anthropogenic Emissions of Mercury

Estimates are taken or inferred from Lamborg *et al.* (2002) and are for 1990. All values in tonnes per year.

particulate matter. These three forms have distinct levels of solubility, reactivity, and toxicity, and behave differently in the atmosphere and the environment.

Elemental mercury (Hg(0)) can persist for more than a year in the atmosphere in a vapor state, and travels globally with prevailing winds. Most mercury reaching the Great Lakes from distant sources likely arrives in this form. The solubility of elemental mercury in water is quite limited and it is largely not directly available to fish and other living things. It can be transformed to the other forms of mercury, including the reactive form; however, this reaction proceeds very slowly. The elemental form is also most subject to re-emission or volatilization to the atmosphere from water bodies.

Reactive gaseous mercury (RGM)(Hg(II)) deposits much more readily than elemental mercury, as typical atmospheric lifetimes are on the order of hours to days. Therefore, RGM tends to be deposited from a few kilometres to a few hundred kilometres from its source. It is also more soluble in water and more bioavailable than elemental mercury. Its enhanced local and regional deposition, solubility, and relative ease of methylation – forming *methylmercury* (MeHg), a highly toxic and bioaccumulating form – give this mercury species a disproportionately large role in regional ecosystemic impacts.

Mercury particulate (Hg(p)) is mercury within and on the surface of airborne particles, rather than discrete particles of mercury. Typical atmospheric lifetimes for particulate mercury are estimated to be one to ten days, or between that of elemental mercury and RGM. Once deposited, this form of mercury may generally be less bioavailable than the soluble Hg(II) compounds arising after RGM deposition.

In general, any given anthropogenic source of mercury emits all three forms of mercury. The deposition impacts of emissions of the different forms as a function of distance from the source is given in Figure 2. The regional deposition impacts of RGM emissions are on the order of ten times that of particulate mercury which, in turn, is on the order of ten times that of elemental mercury.

Recent studies suggest that the rate and extent of conversion of RGM to elemental mercury in coal-fired power plant plumes has been underestimated (Renner 2004). Current models include a moderate reduction due to the reaction of RGM with sulphur dioxide present in the plume; they do not generally use this hypothesized enhanced reduction. This question is significant in that a rapid conversion of RGM in the plume to elemental mercury would reduce its local and regional deposition impacts. Ongoing experimental work should resolve this issue in the near future, and model chemistry will be altered as necessary.

Measurements of mercury deposition in wet form (in rain or snow) in the Great Lakes basin, while significantly limited, are the best data sets available; dry deposition and concentrations in ambient air (which are the basis for any estimate of dry deposition) are not as well characterized.

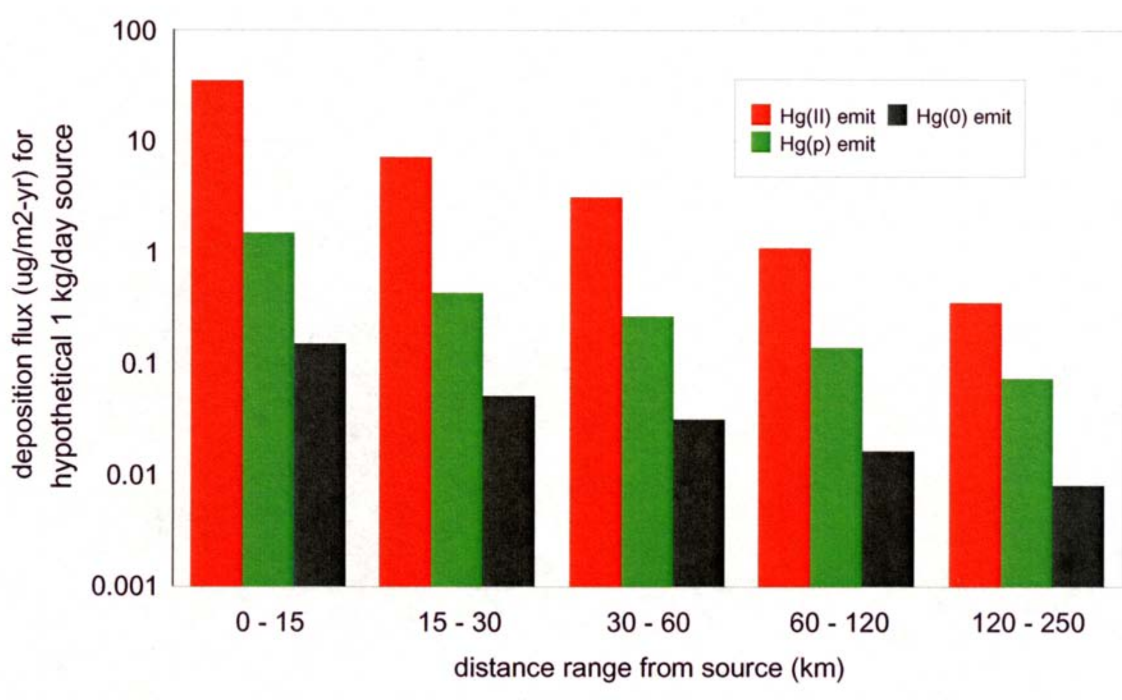


Figure 2. Deposition *vs.* Distance for Emissions of Different Mercury Forms

Logarithmic scale. These data are for Hg(II) [ionic], Hg(p) [particulate], and Hg(0) [elemental] emissions from an effective stack height of 250 metres.

Model Attributes, Requirements, and Challenges

The relative paucity of ambient mercury data is one rationale for deposition modeling; it is unlikely that the resources necessary to monitor wet and dry deposition at all sites of interest will be provided. A model of verified accuracy can be used to provide an estimate of deposition at such locales.

In addition, atmospheric models have the ability to link deposition of persistent toxic substances to source sectors (in the case of mercury, for example, incineration, metallurgical processes, and coal-fired electricity generation) and source regions and, in some cases, to particular large individual sources. Atmospheric models can also be used to forecast changes in deposition that might occur in the future in response to different emission control scenarios.

Atmospheric mercury modeling requires the following:

- Emission inventories to identify the significant sources, including physical and chemical characteristics of the release (for mercury, including speciation among elemental, reactive, and particulate forms).
- An understanding of possible chemical reactions during transport from source to receptor site.
- A means to mathematically express the meteorology necessary for movement of the pollutant (wind velocity, pressure, humidity, precipitation, and other variables).
- Algorithms to estimate wet and dry deposition.
- Available measurements to evaluate the accuracy of model outputs.

Figure 3 is a simplified illustration of the behaviour of mercury in the atmosphere, and Figure 4 is a schematic diagram of the manner in which the HYSPLIT model attempts to mimic this behaviour.

The quality of model outputs is directly related to the quality of the input information. With some exceptions, most notably the coal-fired utility sector, emissions data for total and individual mercury species from various source sectors derived by direct measurement is limited or nonexistent. Estimation techniques such as mass balances and calculated emission factors are widely used in the environmental engineering field. However, particularly in the case of a multi-species contaminant such as mercury, direct source measurements are preferable. Temporal variation in these data is also seldom examined, although many sources would be subject to scheduled and unscheduled interruptions in their operations as well as fluctuations in the extent of their process activities.

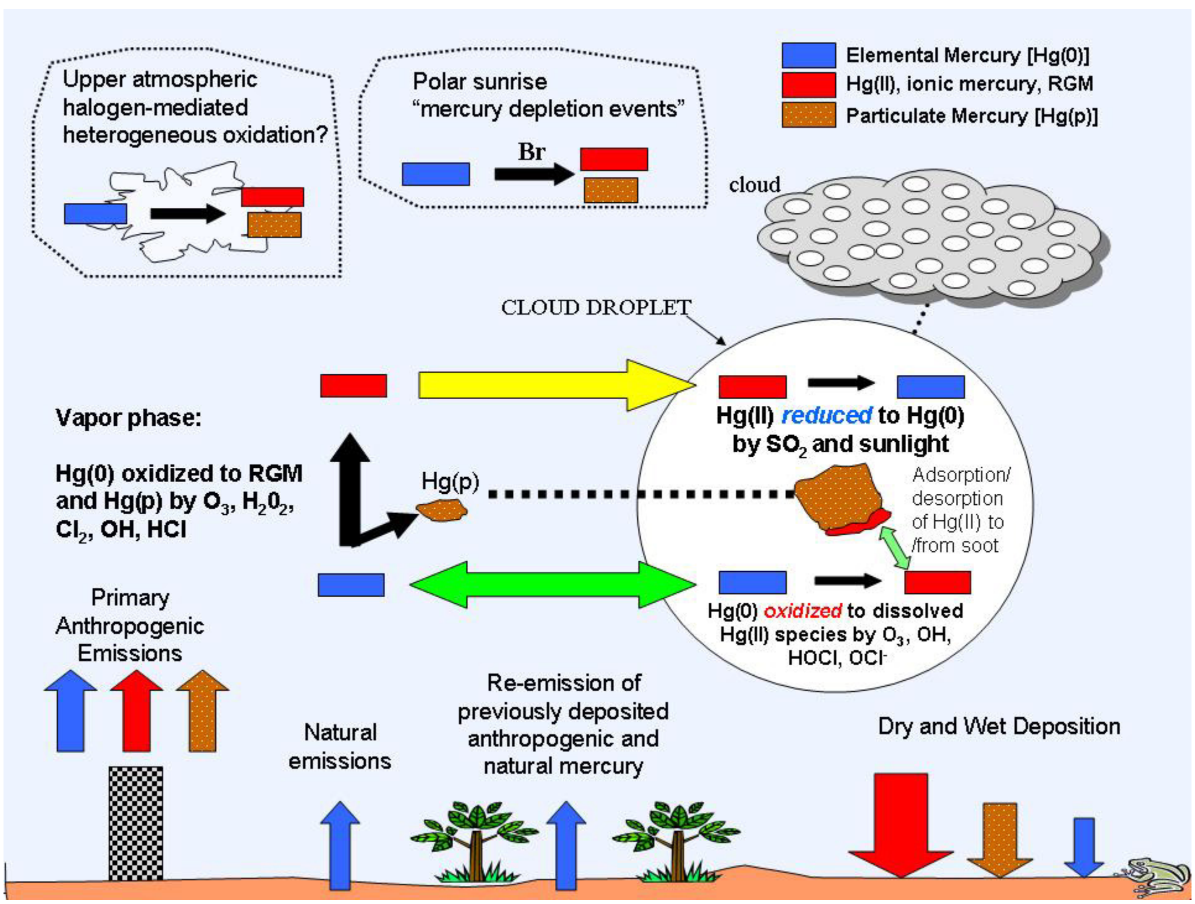


Figure 3. Simplified Mercury Transport and Behaviour in the Atmosphere

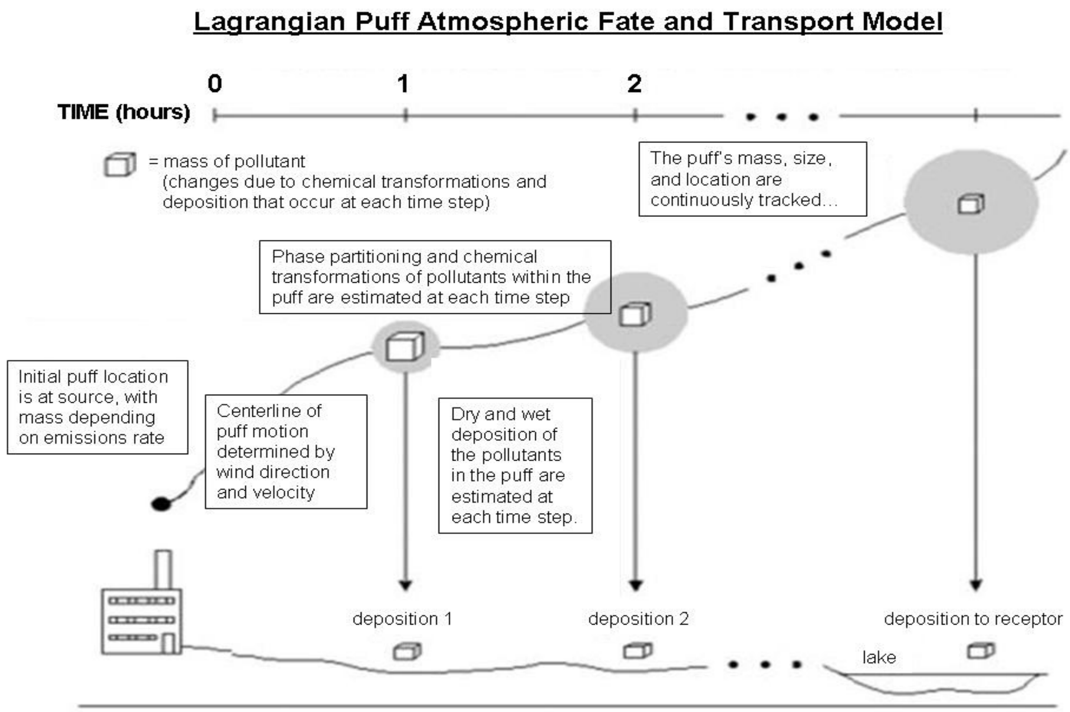


Figure 4. Schematic of HYSPLIT Model

Representation of the complexities of atmospheric chemistry — including reactions with other gases such as chorine and bromine — is imperfect, as are the mechanisms used to estimate the nature and extent of wet and dry deposition. Once a modeling estimate of wet or dry deposition is developed, the relative paucity of wet deposition measurements and ambient mercury concentrations in air (which are necessary to estimate dry deposition) limits the extent to which the modeled estimate can be verified.

Recent Model Outputs – Lake Ontario/Great Lakes

Over the last few decades, several models have been developed whose estimates agree reasonably well with available ambient measurement data. New deposition estimates have been derived from 1999-2001 U.S. and 2000 Canadian emissions inventories. The same 1996 meteorological data set, with its 180 square-kilometer grid structure used in earlier modeling calculations described in the previous Priorities Report, has again been applied. To determine deposition to large water bodies such as the Great Lakes these data should be adequate. More refined and recent meteorological data sets are available and to some extent their use could improve the accuracy of these simulations.

A complete set of deposition estimates for mercury emitted by U.S. and Canadian sources for all five lakes has been developed. As the IAQAB project focuses on Lake Ontario, the calculated values for this lake are presented first, followed by selected information on the entire basin.

Figure 5 shows a binational view of significant sources of mercury to Lake Ontario; it indicates that, while the great majority of significant sources are in the eastern United States, a few more distant sources in both countries have an appreciable impact on the lake.

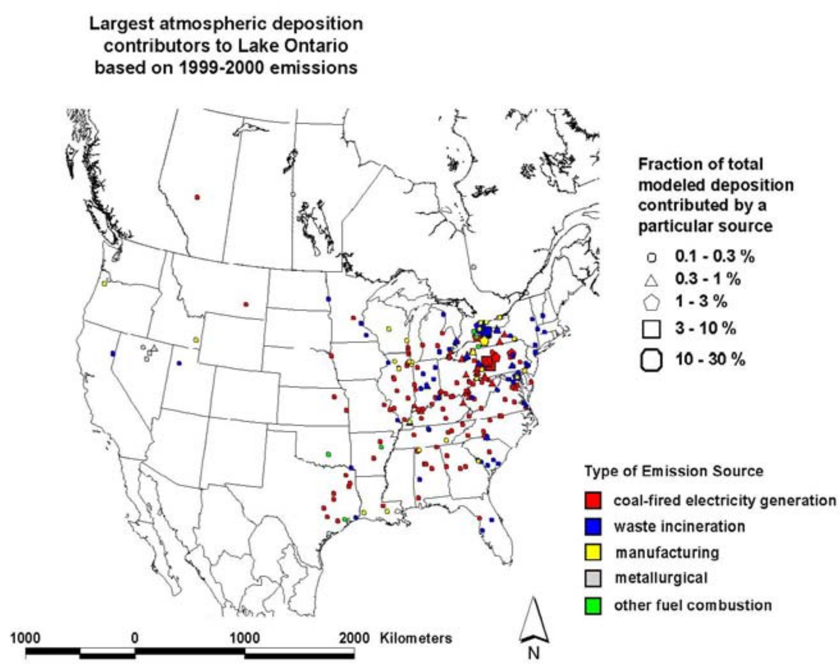


Figure 5. Significant Sources of Mercury to Lake Ontario

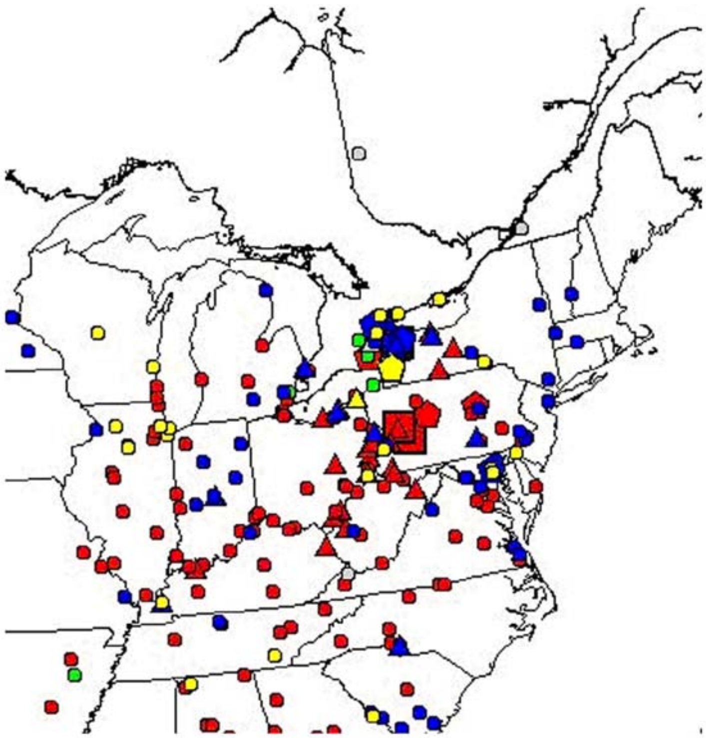


Figure 6. Ranking of Source Sectors Contributing Mercury to Lake Ontario

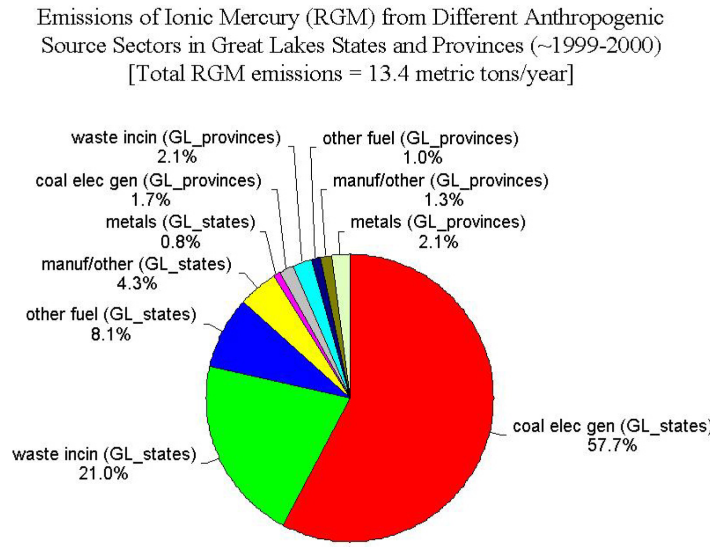


Figure 8. Distribution of Source Sector Mercury Emissions in the Great Lakes Region

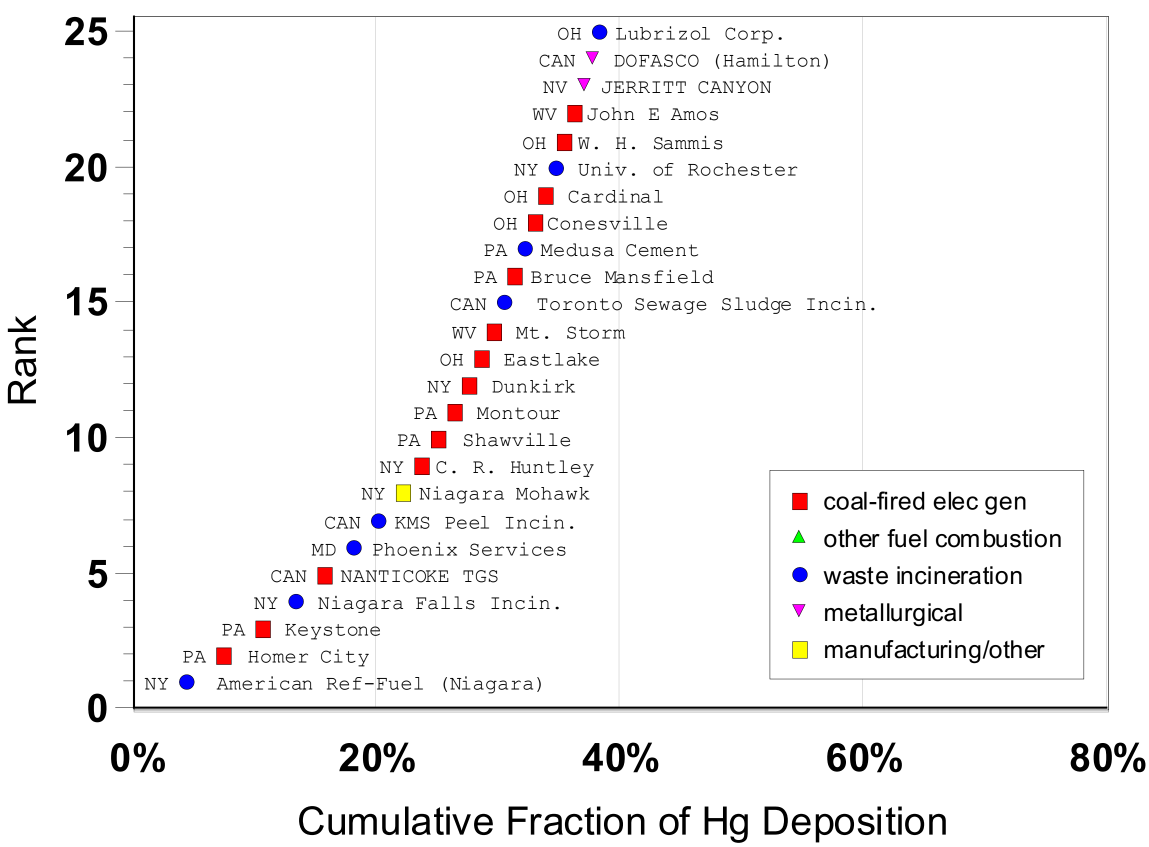


Figure 7. Top 25 Sources of Mercury to Lake Ontario

Figure 6 presents the largest sources on a regional basis, using the same source code as for Figure 5. Figure 6 presents a ranking of the various source sectors, reinforcing the predominance of the coal-fired utility sector.

Figure 7 identifies the top 25 sources and their estimated contribution to the total mercury deposition to Lake Ontario. These rankings are relative and the deposition qualities associated with individual facilities should not be considered definitive. However, the source sectors represented are consistent with the distribution of source sector emissions in the Great Lakes region as shown in Figure 8.

The models confirm the dominance of the coal-fired utility sector as a source of deposited mercury to Lake Ontario. While an Ontario facility (Nanitcoke Generating Station) is in the top five of individual sources of mercury to the lake, the other 13 coal-fired stations are in the United States, several in the Ohio River valley.

The predominance of the coal-fired sector on deposition to the surface waters of the Great Lakes is apparent as well in Figures 9 and 10. Figure 11 illustrates the contribution of various source sectors to Great Lakes deposition. The dominance of the coal-fired utility sector is again evident. Because this is a regional view, a few sources located in the western portion of both countries that made an appreciable contribution to mercury deposition in the basin are not displayed.

More recent emissions data for U.S. and Canadian sources (year 2000) are now available. These data were entered into the model and the results, illustrated in Figure 12, reflect a reduction in deposition to individual Great Lakes from U.S. and Canadian anthropogenic sources. Much of this reduction appears consistent with significant curtailment of emissions from U.S. municipal and medical waste incinerators. The origin of the great bulk of the estimated deposition to the lakes continues to be from U.S. sources.

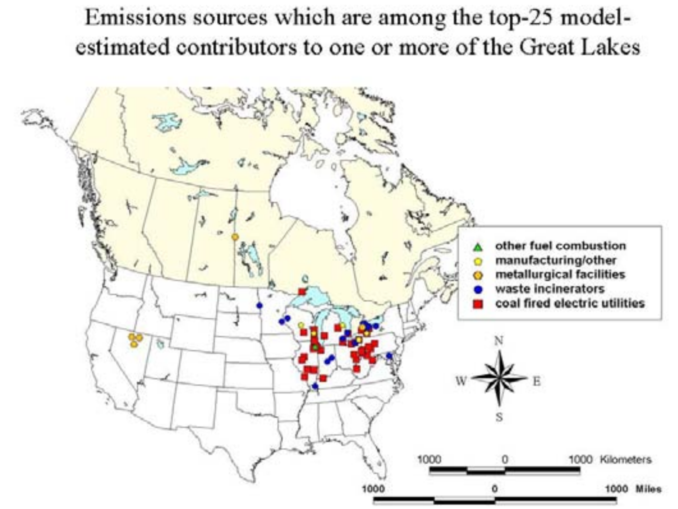


Figure 9. U.S. and Canadian Source Contributions to Great Lakes Mercury Deposition

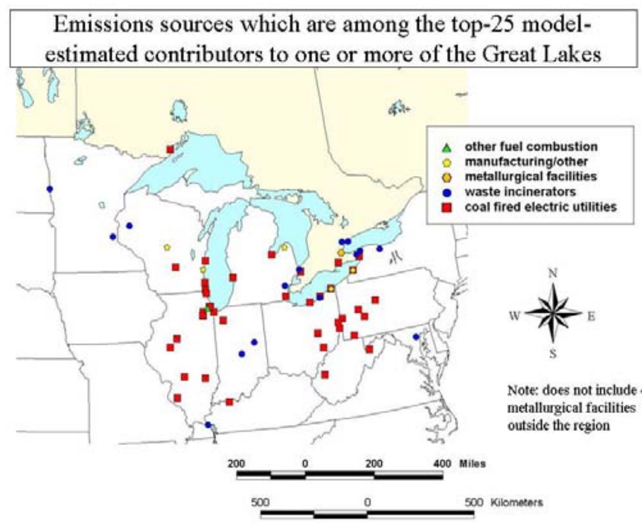


Figure 10. Regional Source Sector Contributions to Great Lakes Mercury Deposition

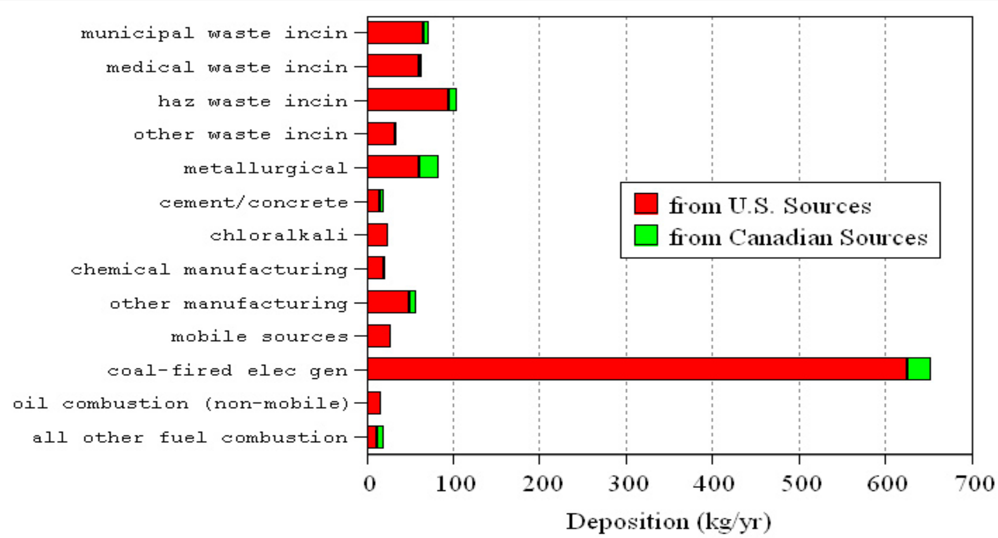


Figure 11. Relative Significance of Source Sectors on Great Lakes Mercury Deposition

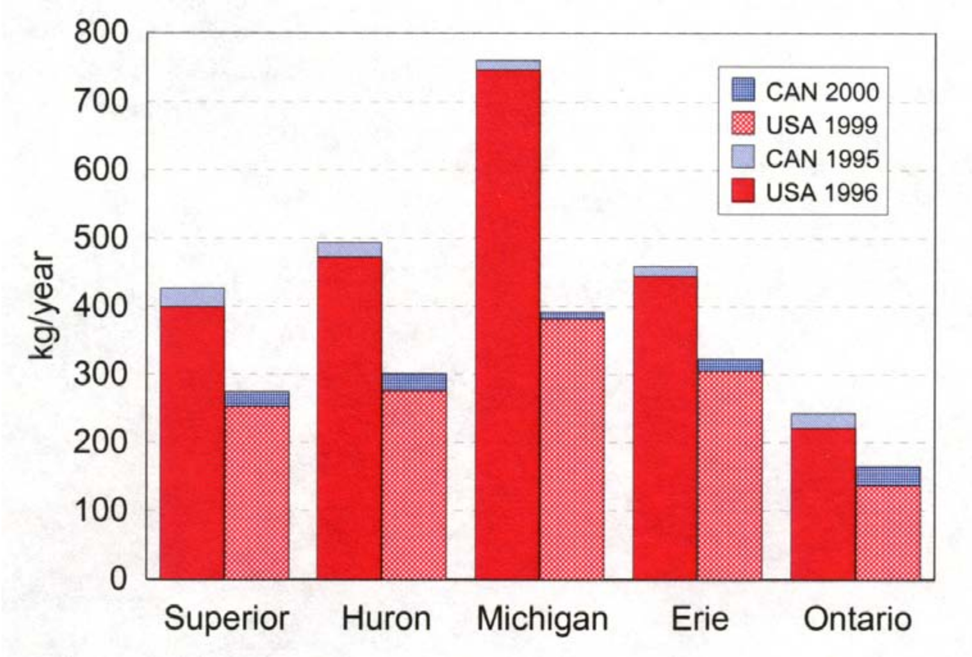


Figure 12.
Changes in Estimated Annual Mercury Deposition to Individual Great Lakes – 1996 to 2000

Model Evaluation

Several uncertainties associated with atmospheric deposition modeling have been outlined previously, such as the paucity of ambient mercury data for evaluation; the limited direct measurement of mercury source emissions, particularly of individual species; concerns over the spatial resolution of meteorological data; and the adequacy by which significant atmospheric chemistry and deposition surface phenomena are captured in the model. The impact of these factors on the quality of the model estimates can be inferred through comparison with available ambient measurements of mercury. Some comparisons to estimates associated with the Lake Michigan Mass Balance Study were presented in the *2001-2003 Priorities Report*. Such limited comparisons increase confidence that current model outputs are indicative of mercury sources of significance and their relative impact.

Data available for mercury-model evaluation are primarily from wet deposition measurement programs. However, wet deposition data alone are not adequate to fully verify model outputs. Atmospheric concentrations of the different forms of mercury – at ground level and also at different heights in the atmosphere – are also needed, and such data should be speciated to the greatest extent possible. The highest level of routine "speciation" information available is the categorization of atmospheric mercury into the three forms discussed above. Even for this limited categorization, there are few data collected and the data are not generally available publicly. The several individual mercury compounds comprising the reactive gaseous and particulate mercury portions are not known and are not being measured – at least not routinely, and perhaps not at all. The lack of more specific identifiers is a significant hindrance to the evaluation and improvement of atmospheric mercury models.

The Mercury Deposition Network (MDN) determines wet deposition in rain or snow on a weekly basis at approximately 80 relatively isolated sites in the U.S. and Canada. The wet measurements have spatial and temporal limitations, including relative isolation from sources, and a preponderance of measurements of total mercury without speciation at most sites. Notwithstanding these limitations, a comparison between these data and model outputs is instructive.

Figure 13 gives a comparison of model outputs using 1996 emissions data. Wet deposition concentrations are measured at the nine MDN sites within 250 kilometres of the Great Lakes. The displayed range of model outputs results from predicted precipitation as forecasted in the NOAA Nested Grid Model and the actual precipitation measured at the individual MDN sites. With the exception of the estimate at site MN16, the model outputs agree reasonably well with measured wet deposition on the linear deposition scale. Model estimates are consistently lower than measurements, again with the exception of the MN16 site, which would be anticipated given that natural emissions and anthropogenic emissions from sources outside the U.S. and Canada are not modeled. But, all of these would be represented in the MDN samples.

The Cooperative Programme for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe has carried out an atmospheric mercury model intercomparison project from 1999-2005 involving experts from around the world. Model results were compared against a variety of ambient monitoring data, including monthly wet deposition measurements at nine monitoring sites in Europe (Ryaboshapko *et al.* 2005).

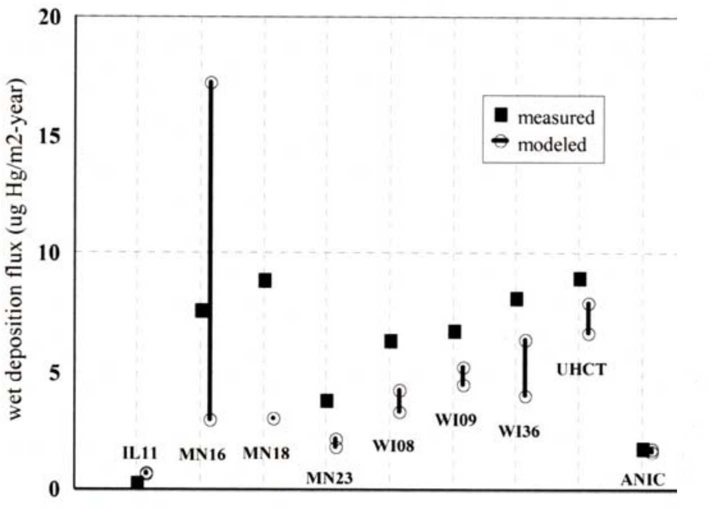


Figure 13. Model Estimates of Mercury Deposition Flux Compared to Wet Deposition Measurements in the Vicinity of the Great Lakes

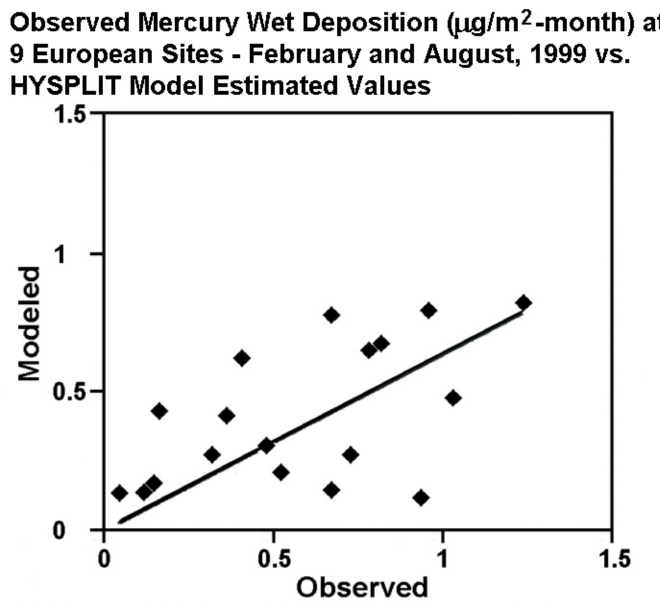


Figure 14. Observed Mercury Wet Deposition at Nine European Sites – February and August 1999 *vs.* HYSPLIT Model Estimated Values µg/m^2- month

In general, HYSPLIT performance was comparable to other participating models in the European program and produced results reasonably consistent with ambient measurements. In Figure 14, the model-predicted deposition is reasonably consistent with wet deposition measured monthly at the nine European sites. Indeed, 66 percent of the results were within a factor of two, 88 percent of the results were within a factor of three, and 94 percent were within a factor of five. This level of agreement was comparable to that achieved by other participating models.

Outputs by mercury species from the European comparison are given for individual sites in Figures 15, 16, and 17. The comparisons for elemental and particulate mercury at the Neuglobsow and Zingst sites respectively are quite good; the comparison with measured and modeled RGM at Aspvreten is still within the anticipated range.

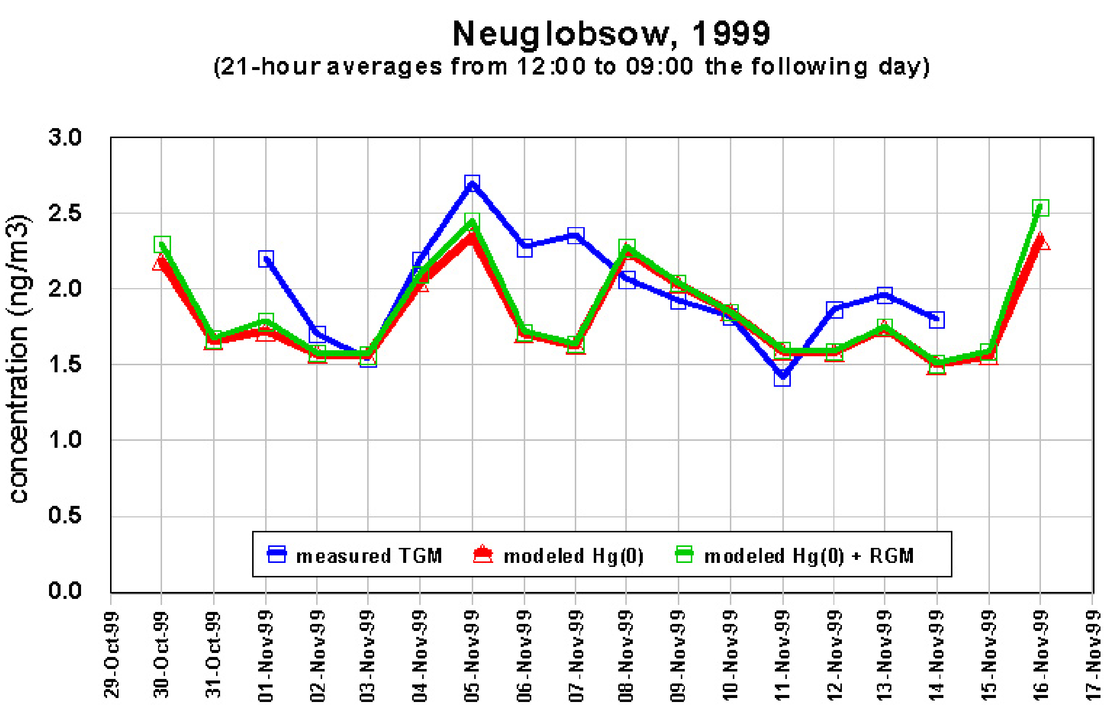


Figure 15. Comparison of Measured Total Gaseous Mercury Concentrations to Modeled Elemental and Elemental Plus RGM Estimates – Neuglobsow Site

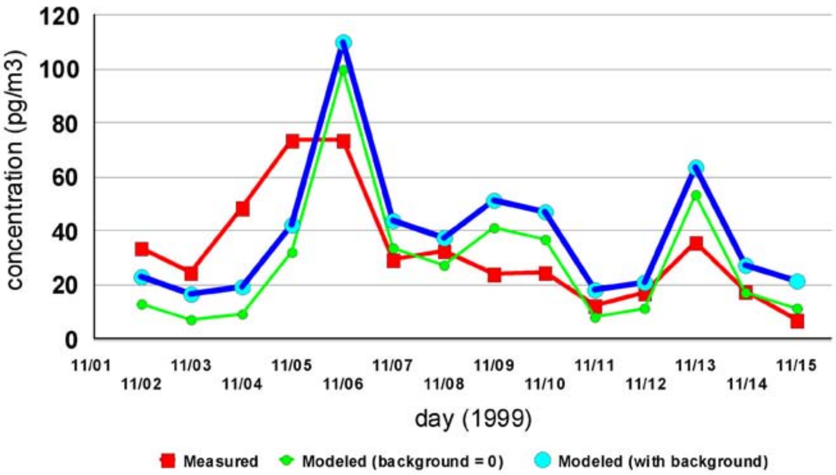


Figure 16.
Comparison of Measured Particulate Mercury Concentrations with Modeled Particulate Estimates – Zingst Site

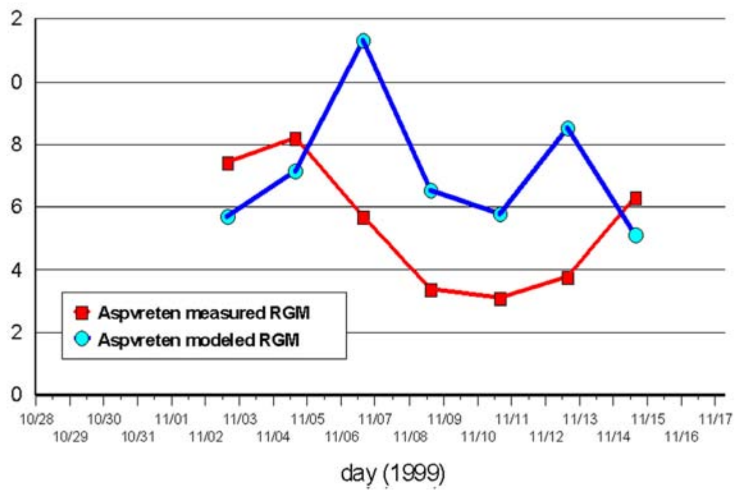


Figure 17.
Comparison of Modeled Reactive Gaseous Mercury Estimates to Measured Concentrations – Aspvreten Site

These results illustrate that while numerous uncertainties are associated with several elements of the HYSPLIT model, the model's estimates of mercury deposition are indicative of the relative contribution of various sources and source sectors to deposition in Lake Ontario and the Great Lakes basin.

Planned Model Extensions

The HYSPLIT atmospheric fate and transport model for mercury is being extended to include natural emissions and re-emissions, as well as emissions on a global scale. These extensions will provide a more complete estimate of deposition to the Great Lakes and improve source attribution. Since natural emissions and re-emissions are generally in the form of elemental mercury, which is most subject to long-range transport, mercury from these additional and most distant sources is most likely arriving in the Great Lakes region in the elemental form. As elemental mercury tends to deposit much less than reactive gaseous and particulate mercury, these additional sources should have less impact than regional emissions of reactive gaseous and particulate mercury. This hypothesis will continue to be examined in future work.

Use of higher-resolution meteorological data that is available in the U.S. could provide a more precise model outcome. Actions recommended by the IAQAB in the *2001-2003 Priorities Report*, including improvements to emission inventories and further extension of ambient mercury measurement activities remain valid. An intercomparison of HYSPLIT and other models in a North American context, similar to ongoing work in Europe, would benefit the modeling community and encourage further application of model outputs in policy decisions.

2.2.2 Ecosystem Fate and Food-Web Accumulation Overview

The overarching, long-term goal is to develop a comprehensive process model for policy makers that can be used to investigate how various regulatory strategies for mercury will affect human exposure in the Great Lakes region. Since the majority of human exposure occurs through consumption of fish containing mercury, this section of the modeling project (illustrated in Figure 18) forms the critical linkage between atmospheric cycling (described in the previous section) and human exposure (described in the following section).

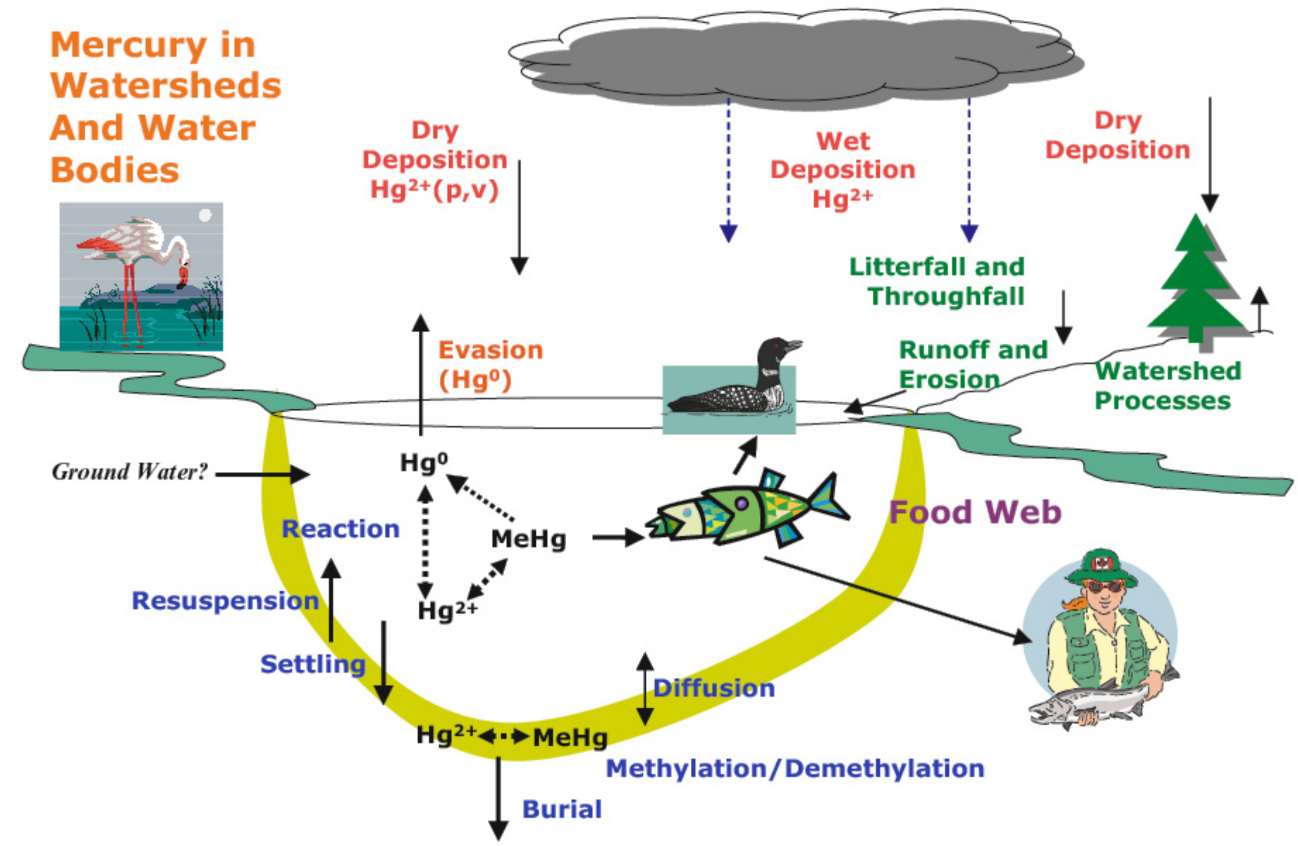


Figure 18. Conceptual Diagram of Environmental Fate Model Components

Most mercury in water, soils, and sediments is present in the inorganic Hg(II) or reactive form. However, only organic mercury (MeHg) biomagnifies in organisms. Under certain environmental conditions, small microbes in the water and sediments known as sulfate-reducing bacteria convert Hg(II) to MeHg. An understanding of the factors controlling MeHg production and accumulation in the water, sediments, and fish is therefore needed to model the bioavailability of mercury to organisms. These processes are the focus of considerable ongoing research and create the scientific background for the environmental fate component of the modeling framework.

Changes in the bioavailability of inorganic mercury and the activity of methylating microbes as a function of sulfur, carbon, and ecosystem-specific characteristics mean that ecosystem changes and anthropogenic "stresses" that do not result in a direct increase in mercury loading to the ecosystem, but alter the rate of MeHg formation, may also affect mercury levels in organisms (*e.g.,* Grieb *et al.* 1990).

Mercury concentrations in fish can increase even when there has been no change in the total amount of mercury deposited in the ecosystem. Thus, environmental changes such as eutrophication, which may alter microbial activity and the chemical dynamics of mercury within an ecosystem, must be considered with emission-control strategies to effectively manage mercury accumulation in the food web.

High concentrations of mercury in predatory fish relative to that present in most water and sediments are caused, in part, by the process of bioaccumulation or biomagnification. Mercury concentrations increase dramatically as larger organisms feed on smaller organisms. Bioaccumulation greatly enhances exposure for humans. For example, one would need to drink approximately 10,000 litres of Great Lakes water to ingest the same amount of MeHg as a single 100-gram meal of a top-level predatory fish. The models are based on the best available scientific understanding of the processes driving mercury bioccumulation in lakes as well as specific data on the composition, biological attributes, and feeding preferences of organisms in Lake Ontario.

The application of an integrated source-receptor, fate, and bioaccumulation model should allow estimation of the potential lag time between reductions in anthropogenic releases of mercury in Canada and the U.S. and declining concentrations in the Lake Ontario ecosystem. However, given current uncertainties regarding the speciation of mercury in the environment and its subsequent entry into the food chain, preliminary results are most valuable for highlighting key areas of scientific uncertainty. These restrict the confidence that can be placed in this type of modeling effort to some extent, but provide a direction for future research.

Despite the quality of their process algorithms, none of the described models can be considered predictive *a priori*. Their credibility rests on their ability to reproduce observed mercury concentration and flux data using reasonable model parameters. All environmental models are under-determined; that is, the use of empirical calibration data within a model allows for multiple possible solutions for the model parameters, all of which could yield a reasonable "goodness of fit" with observed data. Observed data sets are also always incomplete and uncertain. Thus, model calibration is required for each application and the selection of parameters and other aspects of the modeling process unavoidably involve professional judgment.

U.S. EPA is refining and updating a set of existing models (Figure 19) based on the most recent scientific literature. A unified framework will be developed for the aquatic fate and bioaccumulation models to investigate temporal trends in mercury in freshwater ecosystems. The unified-model framework will be calibrated using site-specific data for Lake Ontario. Sensitivity analyses on important model parameters will be conducted to explore assumptions incorporated into the model and to estimate levels of uncertainty in the resulting predictions.

Preliminary Model Application to Lake Ontario

Ecosystem-Fate Model

The ecosystem-fate model is driven by inputs of atmospheric mercury specified by the HYSPLIT model discussed earlier. Lake modeling data have been combined with ecosystem-specific records of total mercury deposition obtained from dated sediment cores to provide the best possible estimates of overall loading to individual ecosystems. By combining these two data sources, the anthropogenic and natural fluxes of mercury in this system are roughly estimated (Figure 20). It is important to note that over the short term, emission-reduction strategies will only affect the anthropogenic component of atmospheric inputs to Lake Ontario, which comprise 60 percent of total deposition.

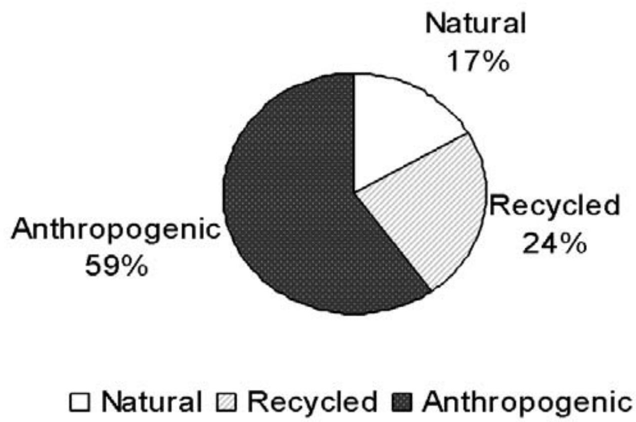


Figure 20. Total Direct Mercury Deposition to Lake Ontario

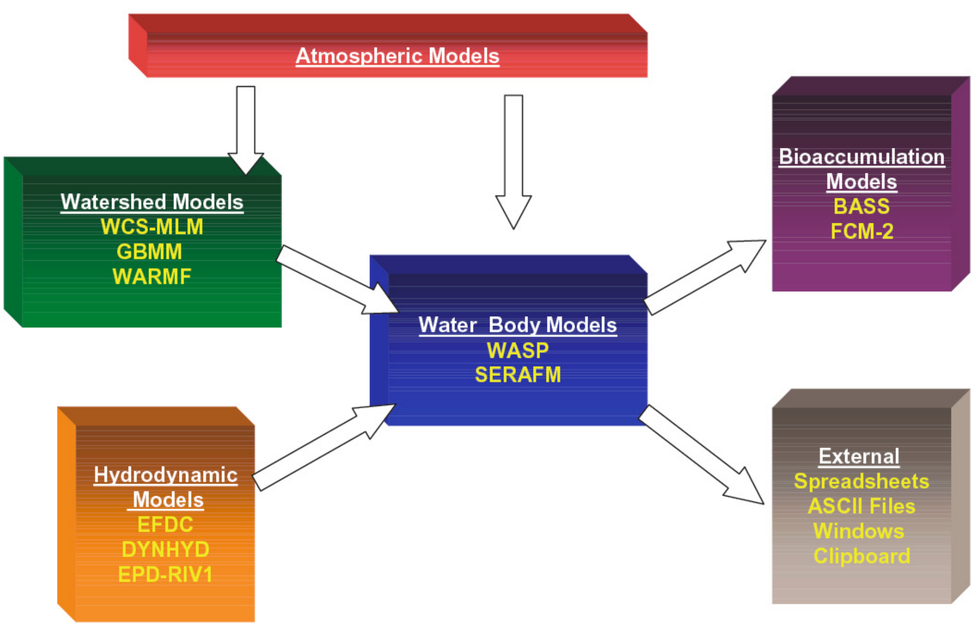


Figure 19. Overview of Linkages Among Waterbody/Watershed Models used by U.S. EPA to Form a Comprehensive Modeling System

In addition to mercury that originates from anthropogenic emissions (estimated from the HYSPLIT model), total direct deposition (~360 kg yr^{-1} in 1995-1996) includes a naturally present and a recycled (continuously deposited and re-emitted mercury) component.

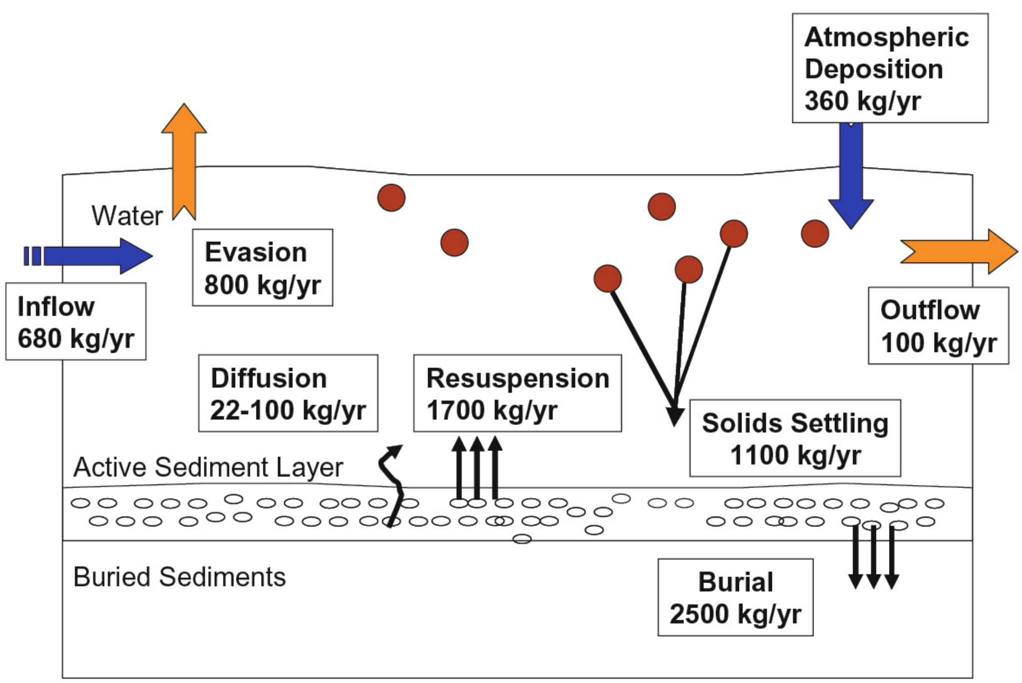
The ecosystem-cycling model considers three principal mercury species (elemental mercury, divalent mercury (RGM or Hg(II)), and MeHg) and various physical processes that affect the distribution of mercury among the water, suspended particulate matter, and bottom sediments.

The benthic (bottom) sediment compartment is divided into an "active layer" and a "truly buried" or inaccessible sediment layer. The active layer can potentially exchange mercury with the water column and buried sediments through resuspension, diffusion, and burial. The active layer is also where conversion of inorganic mercury to MeHg often takes place. Truly buried sediments act as a sink for mercury, removing it from further interaction with the sediment-water interface and benthic organisms. More recent research also shows that methylation in the water column is an important *in situ* source of this contaminant to organisms.

Empirical data from Lake Ontario and the Great Lakes region were used to develop rate constants that describe the rate of reaction and transport of mercury species. Specifically, the model describes transport and reaction as a function of:

- Direct inputs of mercury (*e.g.,* atmospheric deposition and point source and nonpoint discharges to the waters, including industrial, treated sewage, and stormwater runoff);
- Water inflow and outflow;
- Volatilization of elemental mercury (Hg (0)) from the water column;
- Sorption to suspended sediments;
- Deposition of suspended sediments;
- Transfer of mercury from the sediments into the water column via diffusion and resuspension of benthic sediments;
- Burial of sediments; and
- Species interconversions in the sediments and water (*e.g.*, methylation of Hg(II), loss of MeHg to Hg(II), and reduction of Hg(II) to Hg(0)).

This study began with a preliminary, screening-level mass-balance model for mercury in Lake Ontario based on the work by Gobas *et al.* and Mackay *et al.* arising from the 1991 Lake Ontario Mass Balance Workshop sponsored by the IJC, as augmented by E. Sunderland (Figure 21). The preliminary mass budgets for total mercury and MeHg show that most mercury entering Lake Ontario from tributaries, runoff, and atmospheric deposition is scavenged from the water column and deposited to the sediments. Only a small fraction of total mercury inputs is lost in outflowing waters to the St. Lawrence River. This is consistent with other studies that showed Lake Ontario is predominantly a depositional system, and effectively filters contaminants present in inflowing waters from the other Great Lakes and the Niagara River before they are discharged into the St. Lawrence River. This helps to explain why Lake Ontario has the most contaminated sediments of all of the Great Lakes.



The large reservoirs of total mercury in the active layer of the sediment compartment (27,000 kg) relative to present day fluxes (order of magnitude 10^2 to10^3 kg yr^{-1}) indicate that concentrations in the sediment compartment will respond relatively slowly to changes in total loading.

Figure 21. Preliminary, Screening-Level Mass Balance for Total Mercury in Lake Ontario

In contrast, the preliminary mass budget for MeHg suggests that this pool of mercury is much more dynamic in Lake Ontario and largely depends on the rate at which key uncertain processes occur (photodegradation in the water column and *in situ* methylation in the sediments and water column; Figure 22). The persistence and accumulation of MeHg in the water and sediments drives the rate of mercury accumulation in the food web. Thus, other key uncertainties highlighted in this analysis that require further characterization are the degradation processes affecting the stability of MeHg in the water column and factors determining the production and persistence of MeHg in the sediments and water column. Running the preliminary model for total mercury in a time-dependent fashion revealed that it would take several decades for the system to reach a steady state with respect to current inputs.

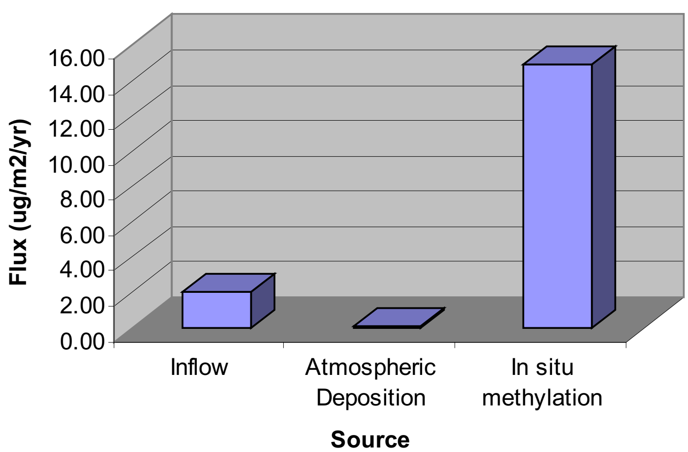


Figure 22. Preliminary Model-Estimated Inputs of Methylmercury to Lake Ontario

In situ methylation is one of the most uncertain terms in the model and has a large influence on model-forecasted fish concentrations.

To augment this initial work, the Grid-Based Mercury Model (GBMM), a watershed cycling model, and the Water Quality Analysis Simulation Program (WASP), an updated, refined ecosystem cycling model, are being applied to Lake Ontario. The WASP and GBMM modeling frameworks are also under development and being refined to reflect advances in mechanistic knowledge of mercury cycling.

WASP is a dynamic, mass balance framework designed to model or estimate contaminant fate and transport in surface water systems, such as lakes, rivers, and streams. The WASP 7 mercury module simulates the behaviour of the three mercury species, Hg(0), Hg(II), and MeHg discussed earlier in three solid types (silt, sand, and biotic solids). Inputs of speciated mercury loadings from atmospheric deposition, direct or point source effluent discharges or associated with flows from rivers, streams, and connective channels are estimated. The associated distribution of mercury species concentrations in the water column and sediments of each reach or portion of the waterway is calculated. Transport processes simulated by the model include multi-directional dispersion and sediment-water exchange, as well as the partitioning or division of Hg(II) and MeHg among silt, sand, and biotic solids, and to dissolved organic carbon.

Mercury species are subject to several transformation reactions, including oxidation of Hg(0) in the water column, reduction and methylation of Hg(II) in the water column and sediment layers, and demethylation of MeHg in the water column and sediment layers. These transformation processes are represented as first-order reactions operating on the total pool of the reactants (*i.e.,* no assumed difference in reactivity of recently deposited Hg(II) and that deposited weeks to years earlier). Reduction and demethylation reactions are driven by sunlight, and so their input surface rate constants are attenuated through the water column using specified light-extinction coefficients. Hg(0) is subject to volatile exchange between the water column and the atmosphere governed by a transfer rate calculated from velocity and depth, and by its Henry's Law constant.

The external watershed loading models to be used include the Watershed Characterization System (WCS) Mercury Tool and GBMM. WCS is a geographic information system (GIS)-based model for calculating annual average soil particle transport and pollutant fate in watersheds. Its mercury transport module was developed from the spreadsheet-based Indirect Exposure Model, Version 2 (IEM-2M) (U.S. EPA 1997), which calculated mercury species concentrations in an idealized watershed and waterbody based on steady atmospheric mercury deposition and long-term average hydrology parameters, including flows and levels. Similarly, the WCS calculates long-term average hydrology and sediment yield, but simulates total Hg(II) in a more realistic, distributed subwatershed network.

Initial background soil mercury concentrations and wet and dry atmospheric mercury deposition fluxes are among the inputs to the model. For pervious subwatershed grid elements, WCS calculates surficial soil mercury concentrations over time using a mass balance. Calculated total mercury in the surficial soil layers is partitioned between the dissolved and particulate phases (in the soil water and on the soil solids). Dissolved mercury is lost from the surficial soil layers through percolation and runoff. Particulate mercury is lost through water-runoff erosion. No wind resuspension is included in the model calculations. A fraction of the soil mercury is reduced and volatilized back to the atmosphere. Subwatershed mercury loadings in runoff water and runoff erosion particles are delivered to the watershed tributary system. For impervious areas of the watershed, atmospheric mercury deposition is considered delivered to the tributary system without loss.

GBMM is a watershed mercury modeling system that simulates flow, sediment transport, and mercury dynamics on a daily time step across a grid-based landscape. Developed as a reconstitution and extension of the WCS mercury model, GBMM is composed of six major components:

- An ArcGIS interface for processing spatial input data;
- A basic hydrological module;
- A sediment-transport module;
- A mercury transport and transformation module;
- A spreadsheet-based model post-processor; and
- Links to other models such as WASP and the groundwater Wellhead Analytic Element Model (WhAEM 2000).

GBMM fully uses the grid-processing capacity of the latest ArcGIS technology. The water balance, sediment generation and transport, and mercury dynamics are calculated for every grid within a watershed. Water and pollutants are routed daily throughout the watershed based on a unique and flexible algorithm that characterizes a watershed into many runoff travel-time zones. This mercury module simulates the following key processes:

- Input from atmospheric deposition;
- Assimilation and accumulation in forest canopy and release from forest litter;
- Input from bedrock weathering;
- Transformation in soils;
- Transformation in lakes and wetlands, including reduction and net methylation;
- Transport through sediment and runoff; and
- Transport in stream channels.

By using the grid-based technology, flow and mercury dynamics can be examined at any of several points in the watershed. The model is capable of supporting large-scale watershed modeling with high-resolution raster data sets. The model is programmed in Visual Basic and requires two ArcGIS (version 9.0) components – ArcView 9 and the Spatial Analyst extension.

Food Chain Bioaccumulation Model

The food chain bioaccumulation model for Lake Ontario consists of several sub-models that describe mercury accumulation in plankton, benthic invertebrates, and four fish species at different trophic levels (Figure 23). These species were chosen because they have traditionally been used as biomonitors for persistent bioaccumulative toxics in Lake Ontario and, as a result, contaminant time trend data were available to test the model's performance. The preliminary screening model was adapted for mercury from the original steady-state bioaccumulation model for PCBs. Using a series of first-order rate constants, the model considers the effects of organism weight (growth dilution), diet composition (assimilation efficiency), and excretion rates of mercury when modeling mercury dynamics among different species and different age classes.

The updated food web model applied to Lake Ontario and integrated into the multi-compartment model development is the Bioaccumulation and Aquatic System Simulator (BASS). BASS describes the dynamics of mercury bioaccumulation

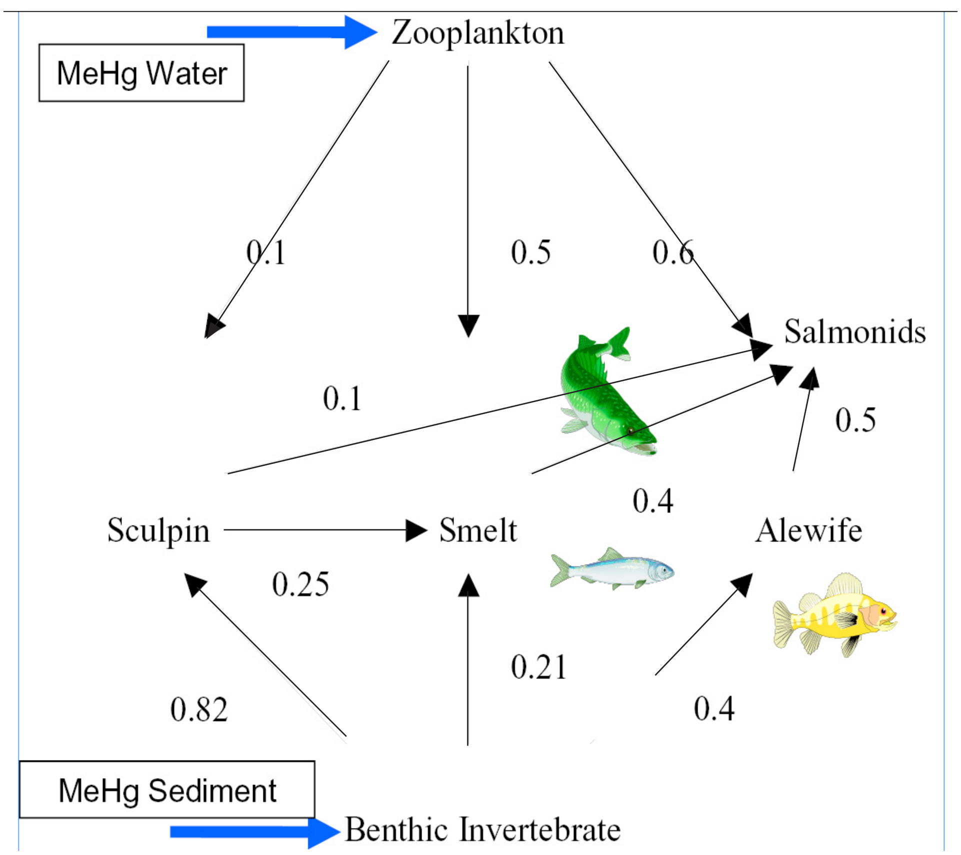


Figure 23.
Dietary Preference of Selected Species in the Lake Ontario Food Web

Based on Gobas *et al.* 1993, 1995

in the food chain with algorithms that account for mercury accumulation among different species and different age classes, using species-specific uptake and elimination terms such as diet composition and growth dilution.

BASS also simulates the population and bioaccumulation dynamics of age-structured fish communities. BASS was specifically developed to investigate the bioaccumulation of chemical pollutants within a community or ecosystem context. However, it can also be used to explore population and community dynamics of fish assemblages exposed to a variety of non-chemical stressors, such as altered thermal regimes associated with hydrological alterations or industrial activities, commercial or sports fisheries, and introductions of non-native or exotic fish species. Contaminants entering each fish through gill exchange and ingestion are partitioned internally to water, lipid, and non-lipid organic material. Internal equilibrium among these phases is assumed to be rapid in comparison with external exchanges. Stability coefficients are specified for the binding of MeHg to available sulfhydryl groups in the fish's non-lipid organic material.

BASS's model structure is generalized and flexible. Users can simulate small, short-lived species (*e.g.,* daces, minnows) and large, long-lived species (*e.g.,* bass, perch, sunfishes, trout) by specifying either monthly or yearly age classes for any given species. The community's food web is defined by identifying one or more foraging classes for each fish species based on body weight, body length, or age. The dietary composition of each foraging class is then specified as a combination of benthos, incidental terrestrial insects, periphyton/attached algae, phytoplankton, zooplankton, and/or other fish species, including its own. There are no restrictions on the number of chemicals or fish species that can be simulated, or the number of cohorts/age classes, or foraging classes that fish species may have.

Model Refinement and Extensions

The models will be refined to incorporate processes that research has demonstrated to be important. Mercury processes are an area of active research and as such are not completely defined; a level of uncertainty exists in model parameterization.

Model application to Lake Ontario will proceed iteratively as new empirical data are used to parameterize the updated modeling frameworks. Empirical data are currently supplemented with parameter values and ranges from the general scientific literature; thus it is possible to perform multiple model calibrations. The most reasonable set of parameters that best fit the observed data at each site will become the base case. From the model response and the underlying science, alternative calibrations will be constructed that should predict a range of ecosystem response times. A more rapidly responding aquatic system, for example, might be characterized by a shallower active sediment layer and higher matched kinetic rate constants, while a more slowly responding system would have deeper active sediment and slower kinetic rate constants. Parameter values for the alternative calibrations must remain within reasonable ranges.

The second step in this application is sensitivity analysis. From the base-case calibration, the suite of models applied to each site will be used to explore and rank the influence of various model parameters and forcing functions on key output variables, including concentrations of total mercury and MeHg in the water body and in fish. The influence of parameters on response time to a step change in loadings (as measured by the 50 and 90 percent response times) will be explored, along with sensitivity to final concentrations. Parameter sensitivity will be expressed as the percent change in the output variable divided by percent change in the input parameter or forcing function. Calculations will be obtained by perturbing individual parameters and forcing functions a fixed percentage above and below the base case. Sensitivity may also be examined for groups of related parameters. The results will provide a better understanding of what factors control the model predictions and what major areas of uncertainty remain.

The third step is scenario projection. Predicted atmospheric deposition fluxes for different proposed management scenarios and the calibrated models will be used to project mercury-reduction trajectories in Lake Ontario. Projections will use the base-case calibration and the rapid and slow parameter sets in order to provide a semi-quantitative uncertainty envelope to the time trends. Results will provide a better understanding of expected differences in ecosystem response resulting from any proposed management actions.

Mercury Experiment to Assess Atmospheric Loading in Canada and the United States (METAALICUS) Study

The development, evaluation, and application of the aquatic fate and food-chain models will benefit greatly by the information accumulated in the Mercury Experiment to Assess Atmospheric Loading in Canada and the United States (METAALICUS) study. This study, a whole-ecosystem experiment examining the relationship between atmospheric mercury deposition and fish mercury concentrations (Harris *et al.* 2004), was described in the *2001-2003 Priorities Report*. Briefly, stable, non-radioactive isotopes of inorganic Hg(II) are added to an 8.3-hectare lake and its 44-hectare watershed in the Experimental Lakes Area in northwestern Ontario. Distinct Hg(II) isotopes are applied to uplands, wetlands, and the lake surface to distinguish the contributions of each source to fish mercury levels. Analytically, the mercury isotopes can be distinguished from each other and from the ambient mercury contained in the lake ecosystem and being continually deposited via natural processes.

Beginning in 2001 and continuing each year since (three years to date), annual wet deposition of atmospheric Hg(II) has increased experimentally three to four-fold relative to long-term average wet deposition rates to the area. Annual mercury additions to

The models will be refined to incorporate processes that research has demonstrated to be important. Mercury processes are an area of active research and as such are not completely defined; a level of uncertainty exists in model parameterization.

the lake surface were 22 g m^{-2} each year. Upland and wetland areas received isotopes at average annual application rates of 21-25 and 25-28 μg m^{-2} yr^{-1} respectively for the 2001-2003 period.

During the first season of additions (2001), concentrations of inorganic mercury in the surface waters of the lake nearly doubled as a result of the mercury isotope (^{202}Hg) added directly to the lake. Relative to the experimental increase in mercury loading to the lake, this is a nearly proportional response for inorganic mercury. Inorganic ^{202}Hg added to the lake surface was also detected as MeHg in the first season in the water column, sediments and biota, including fish.

Concentrations of ^{202}Hg-labelled MeHg in water, sediments, and biota continued to increase in 2002 and 2003. Different response dynamics were observed in the buildup of added isotopic mercury in the form of MeHg in different compartments. Results to date suggest that the system has not yet stabilized in response to the annual isotope additions directly to the lake surface.

Inorganic mercury isotopes added to the terrestrial system were measured in the uplands and wetlands. The upland isotope was observed at low, near-detection levels in lake waters by late 2002, but was not yet detectable in fish as of 2003. Initial efforts to simulate the experiment by a mass-balance model of aquatic mercury cycling were unable to match the rate at which the isotope applied to the lake as inorganic mercury was observed as MeHg in the system. The apparent higher bioavailability for methylation of newly added mercury compared to "older" mercury may be a factor.

Florida Everglades Study

The Florida Everglades Total Maximum Daily Load (TMDL) Pilot Study is one of the best-known investigations of the temporal response of an aquatic system to reduced mercury loading and sets the stage for much of the work described in this report. In 1999 the Florida Department of Environmental Protection and U.S. EPA began a modeling analysis of the environmental cycle of mercury to explore the tools and data needed to perform a TMDL analysis for an atmospherically derived pollutant. Extensive Everglades-specific data are available to support a linked multi-media modeling analysis through the auspices of the South Florida Mercury Science Program, a ten-year multi-agency program of research, modeling, and monitoring studies. Incinerator mercury emissions in southern Florida have declined approximately 99 percent since the mid-1980s as a result of pollution prevention and control policies. Mercury in the fish and wildlife of the Everglades has declined approximately 60 percent from its peak levels in biota in the mid-1990s.

In the Everglades, elevated mercury concentrations in fish are caused by a combination of atmospheric loading, net methylation in water column periphyton, and food-web dynamics (Atkeson 2003). Periphyton and macrophytes influence fish levels through their control of available divalent mercury and MeHg in the water column.

The dynamic Everglades Mercury Cycling Model was applied to investigate changes in fish tissue mercury at one site, with declines in atmospheric mercury deposition as part of the TMDL pilot study (Tetra Tech Inc. 2000). Model simulations showed that fish mercury concentrations were predicted to change by 50 percent of the ultimate response within eight to nine years, regardless of the magnitude of the load reduction. Within 25-30 years, 90 percent of the ultimate predicted response would have occurred. In all cases, the actual magnitude of the change in fish mercury was dependent on the magnitude of the load reduction. In the above simulations, a 3-centimetre thick active-sediment layer was assumed and the model did not distinguish between new and old or "legacy" mercury.

Despite the quality of the modeling, it has limited applicability to other aquatic systems because of unusual attributes of the Everglades. These attributes include:

- **Physiography of the waterbody** — As a flat, shallow, vegetated marshland, the Everglades is atypically vulnerable to atmospheric deposition because of its great surface-to-volume ratio.
- **Climate** — Year-round high temperature and insolation (exposure to sunlight) stimulates chemical and physical processes, promoting rapid aquatic cycling and unusually high production of MeHg.
- **Meteorology** — Easterly trade winds typify the synoptic or regional transport regime dominant during the summer when approximately 85 percent of rainfall and 90 percent of mercury deposition occur. This pattern efficiently brings emissions from the southeast coastal counties of Florida over the Everglades where frequent thunderstorms focus deposition.
- **Sources** — Incineration was the largest emissions category in south Florida through the mid-1990s. A preponderance of emissions was "reactive gas-phase mercury" (RGM or Hg(II)), which tends to deposit on a local scale.
- **Synergy** — Coupled with the meteorology described above, the dominance of emissions as RGM has resulted in an unusually tight local-scale coupling between emissions in southern Florida and local-scale deposition.

2.2.3 Estimating the Uptake of Mercury and Methylmercury by Humans

The Modeling ENvironment for TOtal Risk studies (MENTOR) System

Exposure (and dose) assessment is often the weakest link in any human health risk-assessment process. The estimates of exposures to persistent toxic substances such as mercury and the related dosages determined by different modeling systems can vary significantly even when the models are applied to the same data and for the same exposure scenarios. Dose has been typically assumed to relate to exposure via various empirical factors without accounting for the effects of human activities and for intra- and inter-individual variabilities on physiological uptake and metabolic processes (ATSDR 1992; Georgopoulos and Lioy 1994). To reduce uncertainties associated with modeling human exposure and strengthen human health risk assessment, the Environmental and Occupational Health Sciences Institute (EOHSI) developed the Modeling ENvironment for TOtal Risk studies (MENTOR) system (Georgopoulos *et al.* 1997; Georgopoulos *et al*. 2004a; 2004b).

MENTOR provides a scientifically robust, multimedia, multipathway human-exposure scheme incorporating models, databases, and analytic tools that can estimate probable exposures (and doses) to individuals, populations, and susceptible subpopulations as well as predict and diagnose the complex relationships between source and dose. The objective of the MENTOR project has been to develop, apply, and evaluate state-of-the-art modeling methods for a wide range of environmental applications, using existing models or other means of "filling gaps" in the source-to-dose sequence.

MENTOR links state-of-the-art predictive models of environmental fate/transport and of human exposure and dose. These models are coupled with up-to-date national, regional, and local databases of environmental, microenvironmental, biological, physiological, demographic, and other related parameters. Thus MENTOR is not a new model; it is an evolving open computational toolbox, containing pre-existing and new tools that facilitate consistent multiscale source-to-dose modeling of exposures to multiple contaminants for individuals and populations. The overall goal of MENTOR is to enhance quantitative risk assessments for individuals and populations, and identify critical variables for use in epidemiological investigations.

In an effort to estimate cumulative and aggregate levels of multiple contaminants from multiple or diffuse sources, a set of newly developed components (modules) of the MENTOR system has been linked together in an application-oriented implementation called MENTOR/SHEDS-4M. The acronym stands for MENTOR incorporating the Stochastic Human Exposure and Dose Simulation (SHEDS) approach for Multiple co-occurring contaminants and Multimedia, Multipathway, Multiroute exposures (4M). The MENTOR/SHEDS-4M system simulates through Individual-Based Exposure Modeling (IBEM) and Population-Based Exposure Modeling (PBEM) approaches. Both approaches are driven by the attributes and activities of exposed "real" and/or "virtual" individuals. While IBEM approaches use the information relevant to "actual" individuals (and produce exposure and dose estimates specific for each), the PBEM approaches focus on statistical characterization of exposures and doses of selected populations (at the census tract, county, state, or other designated level). MENTOR/SHEDS-4M combines microenvironmental and human-activities characterization to assess the relative contribution of media (*e.g.,* water, food, dust), pathways (*e.g.,* drinking water, diet, hand-to-mouth), and routes (*e.g.,* oral, inhalation, dermal) to exposures to multiple contaminants (*e.g.,* volatile organic carbons, heavy metals) for individuals or populations.

Methodology

MENTOR contains modules that perform the following seven steps of a comprehensive probabilistic source-to-dose analysis (summarized schematically in Figure 24) for environmental contaminants.

Step 1. Estimation of the multimedia background levels of environmental contaminants (in air, water, and food), for the *area/locations* where the population of interest resides, through examination of the outcomes of selected comprehensive environmental models and/or from field studies.

For exposure assessment purposes, ambient pollutant concentration information available at a local level (such as census tract or neighborhood) is a necessary input to microenvironmental models to estimate population or individual exposures. Typical field-monitoring networks and regional environmental-quality models provide spatial concentration fields too coarse for exposure characterization, making further characterization of local variability necessary. This is accomplished through Spatio-Temporal Random Field (Christakos and Vyas, 1998a, 1998b) as well as Bayesian Maximum Entropy (Christakos and Serre 2000; Serre 1999) interpolation methods incorporated in the MENTOR system.

Step 2. Estimation of multimedia levels (indoor air, drinking water, and food concentrations) and temporal profiles of *environmental contaminants in various specific microenvironments* such as residences, offices and restaurants.

- Air concentrations are calculated using either mass-balance models or linear-regression equations developed from analysis of concurrent indoor and outdoor air measurement data available for particular types of microenvironments (Burke *et al*. 2001).
- Drinking-water concentrations are obtained from regulatory monitoring databases such as the Safe Drinking Water Information System/Federal Version (U.S. EPA 2005b) or field study measurements such as the National Human Exposure Assessment Survey (NHEXAS) (Whitmore *et al*. 1999). If such data are not available, the drinking-water distribution is modeled using the EPANET2 model

(Rossman 2000) that uses water-purification treatment-plant data to obtain the drinking-water concentrations. For a discussion of the application of drinking-water distribution modeling to epidemiological studies, see Maslia *et al.* (2000).

- Food concentrations are obtained from survey studies such as the Total Diet Study (TDS) (U.S. FDA 2004a) and NHEXAS (Whitmore *et al.* 1999).

If case/site specific data is available they can be used by the MENTOR system.

Step 3. Selection of a *fixed-size sample population* to statistically reproduce essential demographics of the population unit used in the assessment (age, gender, race, occupation, education). The demographic attributes are retrieved from databases developed from the 2000 U.S. Census Survey (U.S. Census Bureau 2004). Due to the variability of typical populations, a rather large ("conservative") statistical sample of 500 "virtual individuals" is usually assumed to represent each census tract of the area under study. This approach is used to adequately reproduce the demographic distributions of parameters such as age, gender, housing type, and employment status.

Step 4. Development of *activity event sequences* for each member of the sample population by matching her/his attributes to entries of U.S. EPA's Consolidated Human Activity Database (CHAD) (U.S. EPA 2003a). In order to characterize source-to-dose relationships for an actual or virtual "individual," the analyses must be capable of tracking this individual consistently through his/her activities in space and time. For each simulated individual, the activity diary (if not available from a case-specific study) is selected from CHAD, based on matching demographic attributes (*e.g.,* age, gender, employment status). Metabolic Equivalent of Tasks (METS) values are then assigned for each activity event to calculate associated intake needs (such as inhalation rates, water and food consumption).

The PBEM framework uses a consistent set of variables and information for exposure factors and human-activity patterns to conduct population exposure assessments of multi-pollutants. While the PBEM framework will be used in this application, it will be applied only to a single pollutant: mercury.

Step 5. Calculation of inhalation, drinking water, dietary, and other *intake rates* for the actual or virtual individuals of the sample population, based on the physiological attributes of the study subjects and the specific activities pursued during the individual exposure events.

- The *inhalation rate* is calculated based on the individual's age, gender, and the METS value associated with the activity pursued (see Georgopoulos *et al.* 2005 and references therein).

- The *drinking water and beverage consumption rates* are estimated by extracting survey records matching the individual's demographic characteristics, particularly from the U.S. Department of Agriculture's Continuing Survey of Food Intakes by Individuals (CSFII), the most comprehensive database with information on this issue.

- The magnitude of *dietary intake* of contaminants is estimated by reviewing information on food-consumption rates, composition of food item (recipe file), and contaminant-residue (concentration) data in food. CSFII (Tippett 1999) provides information on food-consumption rates for the general U.S. population. The TDS database (Baker *et al.* 2001; Tao and Bolger 1998) by the U.S. Food and Drug Administration provides information on 1991 to 1999 residue data in 267 types of raw agricultural products that are composites of food items. The U.S. EPA National Exposure Research Laboratory (NERL) dietary module (Xue 2003), using the CSFII and TDS databases as well as a recipe file linking both, has been incorporated into the MENTOR system to estimate dietary intakes of various chemicals. As an alternative, the Dietary Exposure Potential Model (U.S. EPA 2003b) can be used.

Step 6. Combination of inhalation, drinking-water, and dietary-intake rates with the corresponding multimedia microenvironmental concentrations of the contaminant, for each activity event, to assess *exposures*.

Step 7. Estimation of target *human tissue doses* (*e.g.,* lung deposition and clearance of fine particles, kidney and liver dose and elimination) through physiologically based dosimetry and Physiologically Based Toxicokinetic (PBTK) modeling. MENTOR/SHEDS-4M takes a major step beyond any previous similar exposure analysis to calculate target-tissue dose (and corresponding biomarker levels) using PBTK modeling for the entire population considered. This allows model evaluation against biomarker measurements available in the NHANES database and from other studies. The most readily available biomarker data for mercury are from human hair, blood, and urine samples.

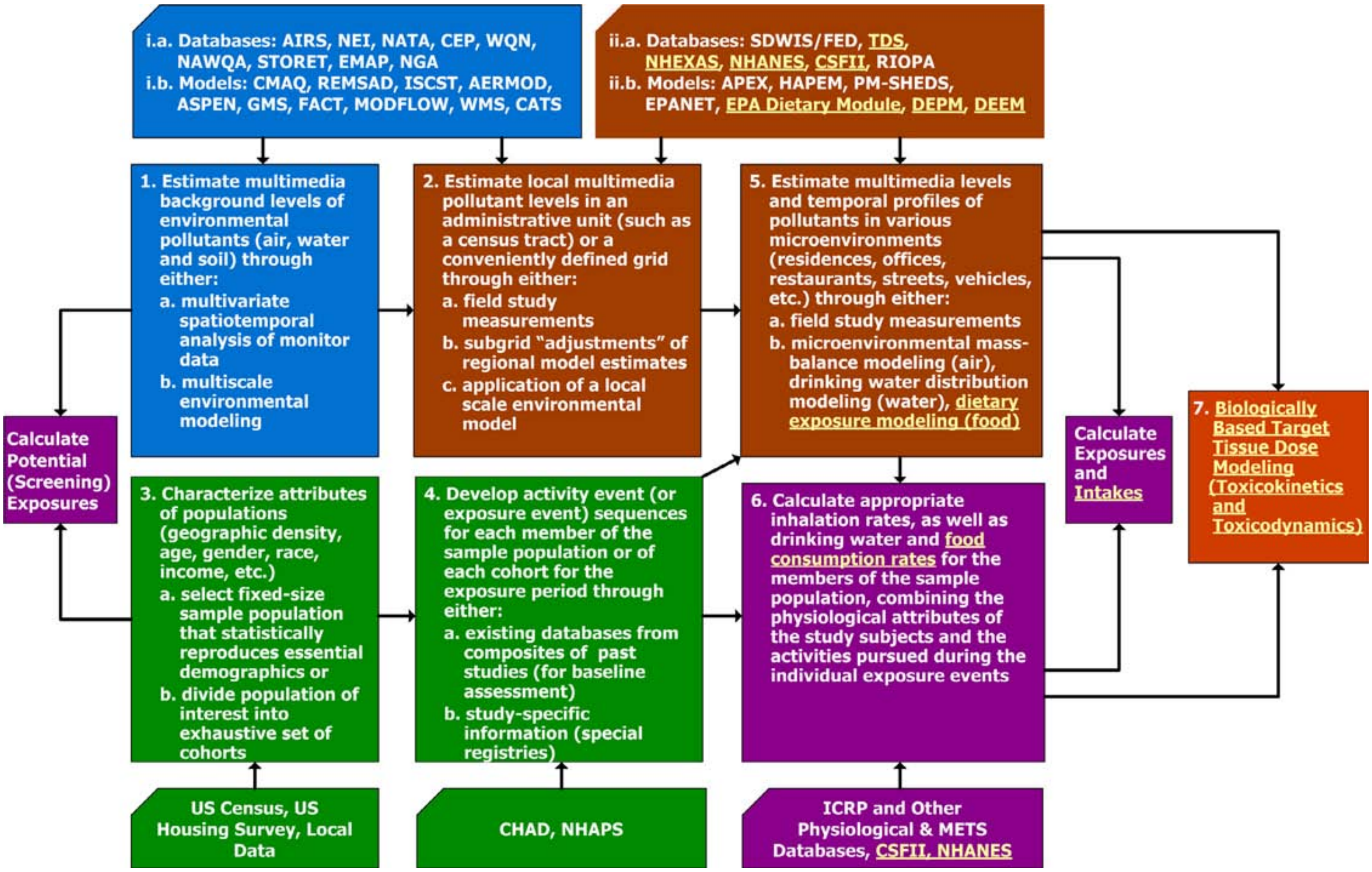


Figure 24. Steps Involved in the Multi-Route Application of MENTOR/SHEDS for Assessing Individual and Population Exposures and Doses to Mercury

**Figure 25.
Case Study Area:
Oswego County, New York**

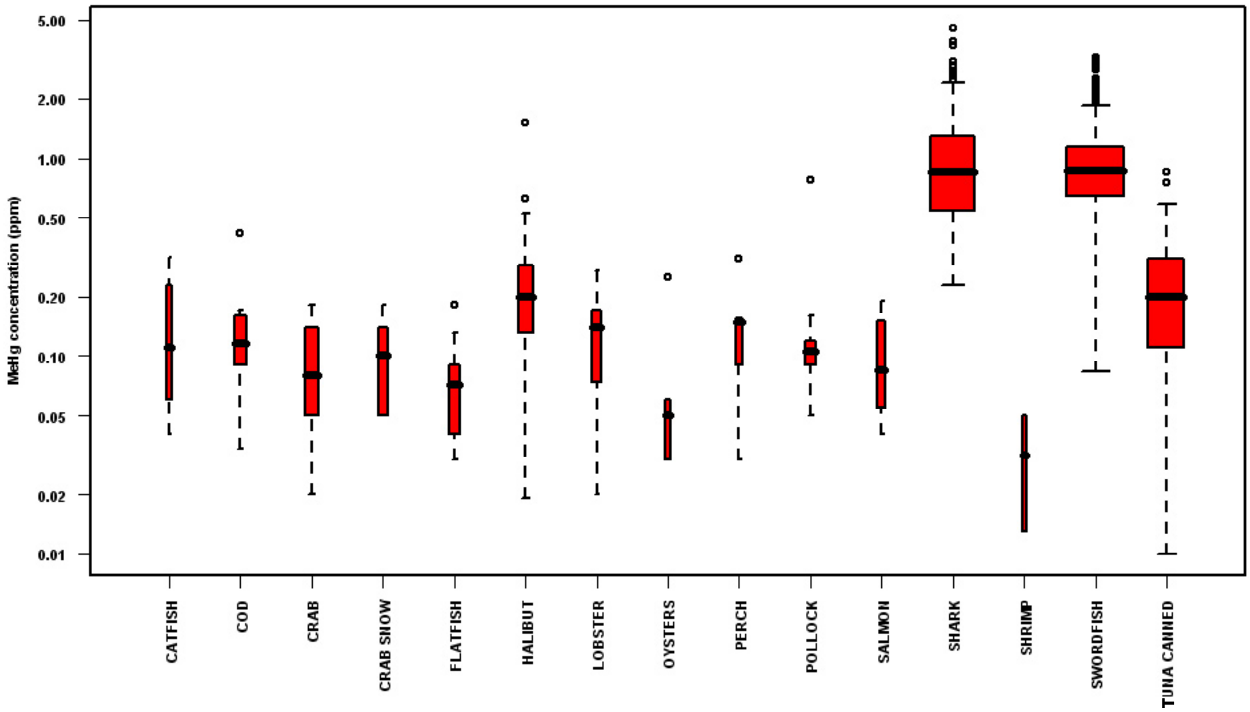


Figure 26. Box Plots Showing Methylmercury Concentrations for Selected Species of Fish Most Commonly Consumed in the U.S. Commercial Seafood Market

Data from U.S. FDA (2004b).

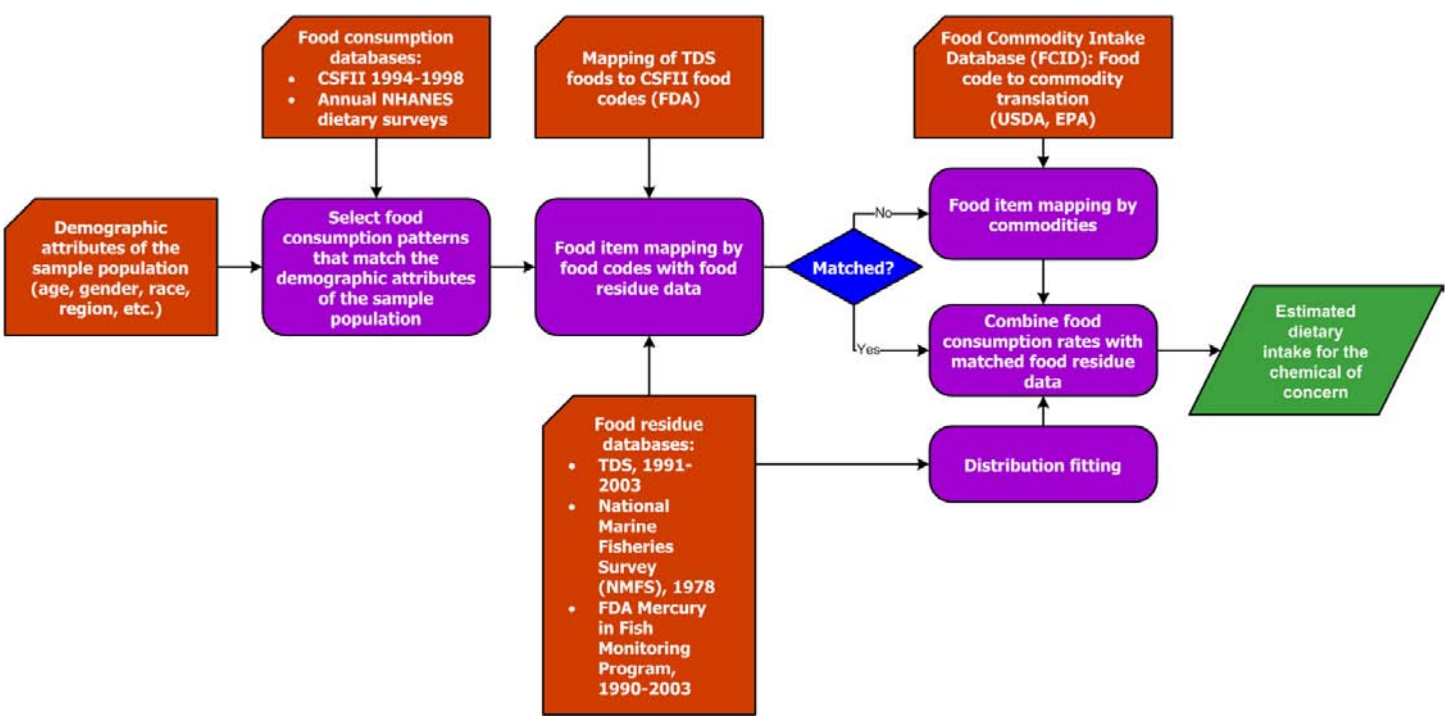


Figure 27. Structure of the Probabilistic U.S. EPA National Research Laboratory Dietary Module

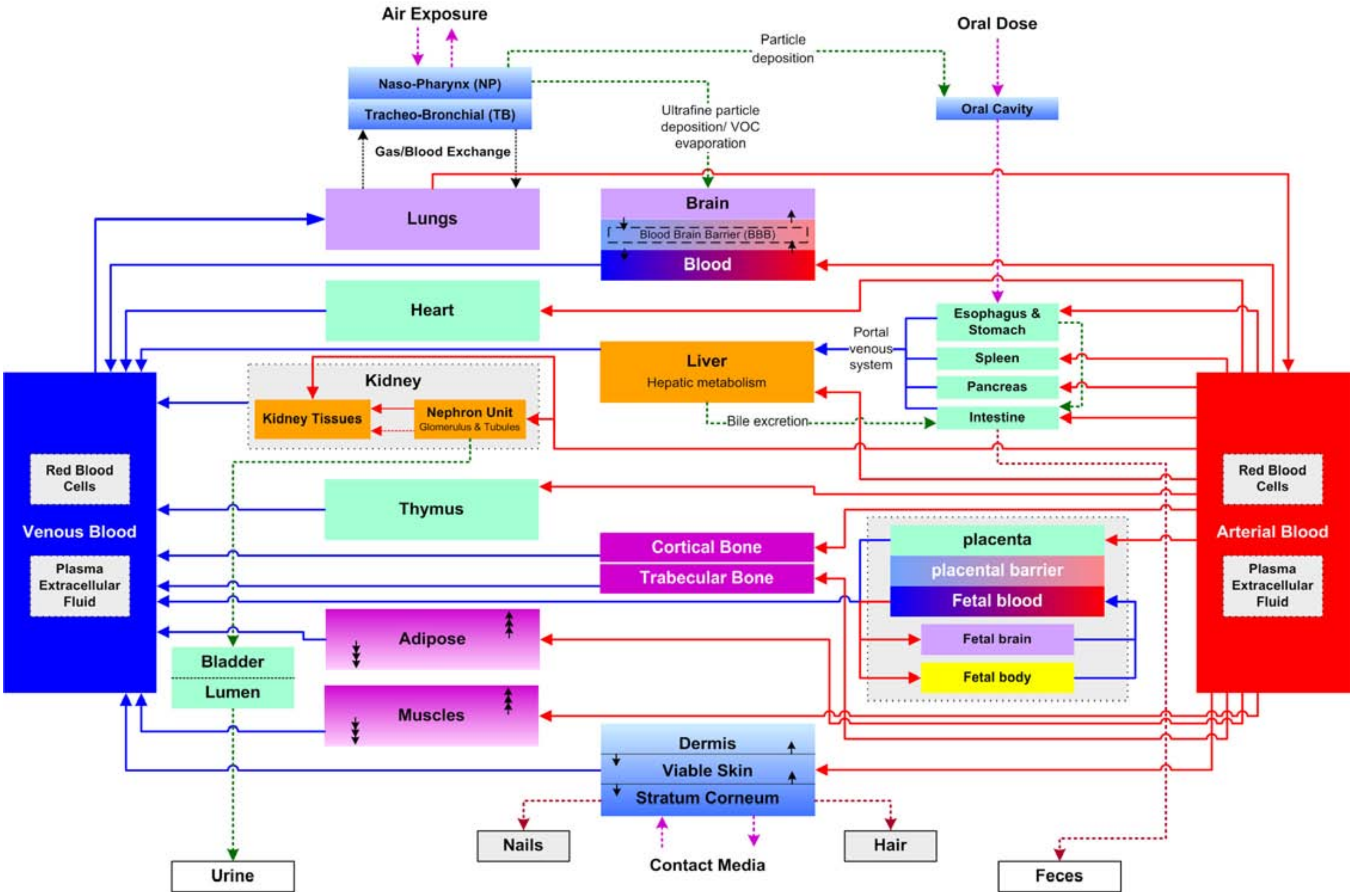


Figure 28. PBTK/BBDR Modules of MENTOR

The modules incorporate age/gender-specific parameter distributions and are designed to support probabilistic assessments of cumulative and aggregate exposures/doses.

Preliminary Case Study

A preliminary case study of human exposure to mercury and MeHg through dietary assessment was conducted for Oswego County, New York using the previously described PBEM approach within the MENTOR/SHEDS-4M framework. This county was selected because it is adjacent to Lake Ontario (see Figure 25). The following describes how comprehensive population-exposure modeling has been implemented into this study.

Steps 1 and 2. The food concentrations of mercury and MeHg were obtained from U.S. FDA's TDS databases (Baker *et al.* 2001; Tao and Bolger 1998) and Mercury in Fish Monitoring Program (U.S. FDA 2004b). The TDS database provides information on the concentration of inorganic mercury in about 280 foods for the general U.S. population from 1991 to 2003. TDS sample collections have generally been conducted four times each year, once in each of four geographic regions of the U.S. (West, North Central, South, and Northeast). Data collected from the Northeast region were used in this study. The Mercury in Fish Monitoring Program provides information on MeHg levels in fish and shellfish. Figure 26 shows the box plots of MeHg concentrations for selected fish species most commonly consumed in the U.S. commercial seafood market.

Further data for mercury contamination of fish species is being sought for the Oswego area. In the interim, some information from the Ontario Ministry of the Environment (MOE) is indicative of the extent of mercury contamination in Lake Ontario. The Ontario MOE guideline for mercury concentration in fish is 0.45 ppm, and estimates for 2003-2004 were that 25 percent of Lake Ontario advisories are due to elevated mercury concentrations. The 2005-2006 sport-fishing guide indicates that mercury contamination accounts for 7 percent of the advisories applicable to Lake Ontario (Ontario MOE 2005).

A study of blood-mercury levels among Ontario anglers and sport fish eaters included two Lake Ontario communities on the Canadian shore: Cornwall and Mississauga. This study was conducted by Health Canada, the Quebec Toxicology Centre, and researchers from the Universities of Toronto and Chihuahua,

The preliminary dietary assessment indicates that the major contribution to mercury exposure for the Oswego County population is due to fish consumption (fresh and canned).

Mexico. The arithmetic mean blood level in Lake Ontario fishers who consumed their catch was 2.8 ug/L. However, the study also presented data from other locales in the Great Lakes that indicated that among Asian Canadian sport-fish eaters the mean was 9.6 ug/L (Cole *et al*. 2004). While none of these data can be considered representative of fishers in the Oswego area, they clearly indicate that any investigation of the Oswego fishing community should consider the possible existence of recreational and subsistence sub-elements within that community.

Step 3. A sample of 10,000 "virtual individuals" was selected to statistically reproduce the demographic characteristics of Oswego County. Based on the year 2000 demographic profile assembled by the U.S. Census Bureau, Oswego County consists of 29 census tracts and has a population of 122,377 persons – 60,402 males and 61,975 females. The median age is 35 years with 76,165 people over 25 years of age and 7,585 under 5 years old. The number of inhabitants over the age of 65 is 13,875. Further characteristics of the county population can be found on the U.S. Census Bureau database.

Step 4. A 24-hour activity diary for each "virtual individual" was selected from the CHAD diaries to match the demographic characteristics with respect to age, gender, and employment status. An activity diary defines each event by geographic location, start time, duration, microenvironment visited, and activity performed. These activity diaries do not account for sport or subsistence fishing events. Additional data are being sought on the level of mercury contamination in fish in local waters and the extent to which such fish are caught and consumed in Oswego County.

Step 5 and 6. The dietary intake exposures of inorganic mercury and MeHg for each member of the simulated population were estimated using the probabilistic U.S. EPA NERL dietary module (summarized schematically in Figure 27). The input databases include CSFII (Tippett 1999), food residue (concentration) distributions obtained from steps 1 and 2, and a mapping profile of food items between food consumption and residue surveys. The algorithm used in this module is assembled using the following procedures.

- Generation of annual eating patterns of the simulated individuals by extracting food-consumption rates from the CSFII database, based on similar demographic variables (such as age and gender) to account for interpersonal variability. Eight daily food-consumption data sets, corresponding to the combination of four seasons and two day types (weekday and weekend), are also randomly drawn from the CSFII database for each simulated individual.
- Allocation of the food-consumption data (by food items) to different categories of foods in the residue survey such as TDS, using the mapping profile. In the food-consumption surveys, more detailed information is often collected on the types and amounts of foods consumed. Significantly fewer food items are listed in the food-residue surveys compared to the food-consumption surveys. The food items in consumption surveys have been grouped (or mapped) together according to their similarity to the food categories in residue surveys.
- Combination of the food-consumption rates with the corresponding residue data of inorganic mercury and MeHg to estimate dietary intake for the simulated individual.

Preliminary Findings and Discussion

The preliminary dietary assessment indicates that the major contribution to mercury exposure for the Oswego County population is due to fish consumption (fresh and canned). Minor dietary sources are liver, chicken, and some vegetables.

Uncertainties related to dietary mercury exposure/dose modeling through the fish-consumption pathway may come from factors such as population diet, regional economy, and season. The uncertainties in population diet may include amounts of fish consumed, fish species consumed, and fish-preparation method. The regional economy factors may include the proportions of local *vs*. imported fish on the market, pricing and availability, processing, and storage. Seasonality may influence the fish species, fish maturation, and fish size taken by local anglers.

Cornell University surveyed 17,000 fishers statewide and 5,000 fishers along the New York portion of Lake Erie, the Niagara River, Lake Ontario, and the St. Lawrence River by mail and phone (Cornell University 1996). Oswego County was among the included areas. The survey indicated that a majority of area fishers were from the region and ~ 25 percent were from out of state. The number of anglers in Oswego and adjacent Jefferson County was 87,300, which totaled over one million annual cumulative days of fishing effort. In these counties, effort was roughly equally divided between cold-water species (lake, rainbow, brook, brown and steel head trout, coho and Atlantic salmon) and warm-water species (walleye, bass, crappie, northern pike, perch). As noted earlier, further assessment of local fishing practices and related fish consumption is necessary to further improve the MENTOR output.

The U.S. EPA NERL dietary module, which has been linked with the MENTOR/SHEDS-4M system, can explicitly address variability and uncertainty in the food concentration and consumption databases. The population-specific mercury-intake distributions calculated by the dietary-exposure model will be used as inputs for the calculation of target human-tissue doses (*e.g.,* brain, kidney, breast milk, fetus) using the "multi-metal" PBTK module (depicted in Figure 28) of the MENTOR/SHEDS-4M system. This system has the capability to address age, gender, lifestyle differences, physiological variability, and physicochemical and biochemical variabilities. Future efforts should focus on incorporating biomarker data in the exposure/dose framework to evaluate applicability and performance of predictive models.

2.3 Model Integration

2.3.1 Preliminary Static Integration of Atmospheric and Aquatic Processes

To date, the multi-compartment model for mercury in Lake Ontario has been integrated in a static fashion. For example, the HYSPLIT deposition model was used to determine estimates of mercury loading to the lake, and this and other inputs were used by the environmental-fate model to calculate a concentration of total and MeHg in water and sediments. The bioavailable mercury concentration could then be applied in the food-chain model to estimate mercury uptake and accumulation. Various simplifications were applied to achieve a first estimate. Fish mercury concentrations forecast using the bioaccumulation model could then be used as inputs to the MENTOR modeling system.

2.3.2 Future Model Integration

In addition to updating and refining existing modeling frameworks, the next goal of the modeling team is to establish a dynamic linkage between the HYSPLIT and aquatic-cycling models. Ultimately, the goal is to dynamically model evasion of elemental mercury from aquatic and terrestrial systems as an input to the source-receptor model (see Figure 29). Accounting for this "recycling" of mercury at the air-water and soil-air interface will enable more accurate forecasts of *net* deposition to aquatic and terrestrial surfaces.

An overall schematic of the proposed modeling is given in Figure 29. The atmospheric fate-and-transport model and the aquatic fate-and-cycling model will be dynamically linked with each program in continual interaction with the other. The primary purpose of the linkage between these two models is to accurately estimate the flux of mercury across the air-water interface. This flux will then be used by both models as the flux across their respective boundaries. The time scale for the linkage will be relatively fast, on the order of hours.

The linkages between the aquatic fate and cycling model and subsequent models will be less dynamic with one-way information flow, and will take place on longer time scales. The time scales and linkages will be dictated by the physical nature of the systems being simulated. Input data – the leftmost column in Figure 30 – will be assembled and/or developed as needed. Examples of data sources are provided in parentheses. Each model will be evaluated by comparing model predictions with ambient measurements, examples of which are shown in the rightmost column.

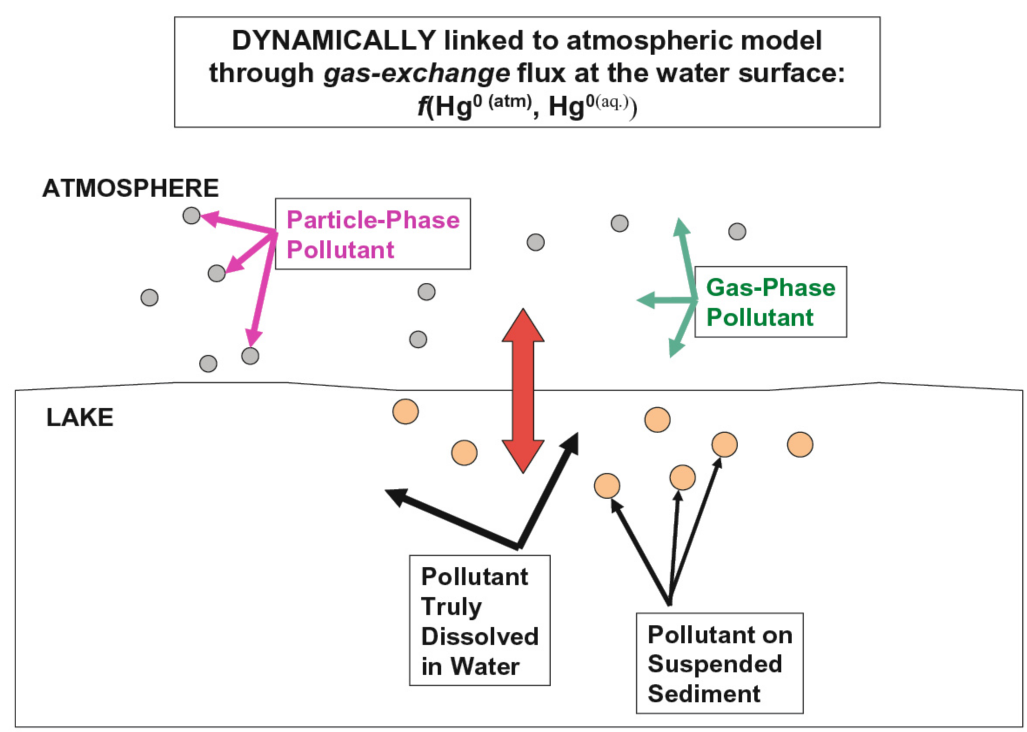


Figure 29. Conceptual Model of Dynamic Linkage between the Air-Water Interface for Mercury
To be implemented in the multi-compartment modeling project.

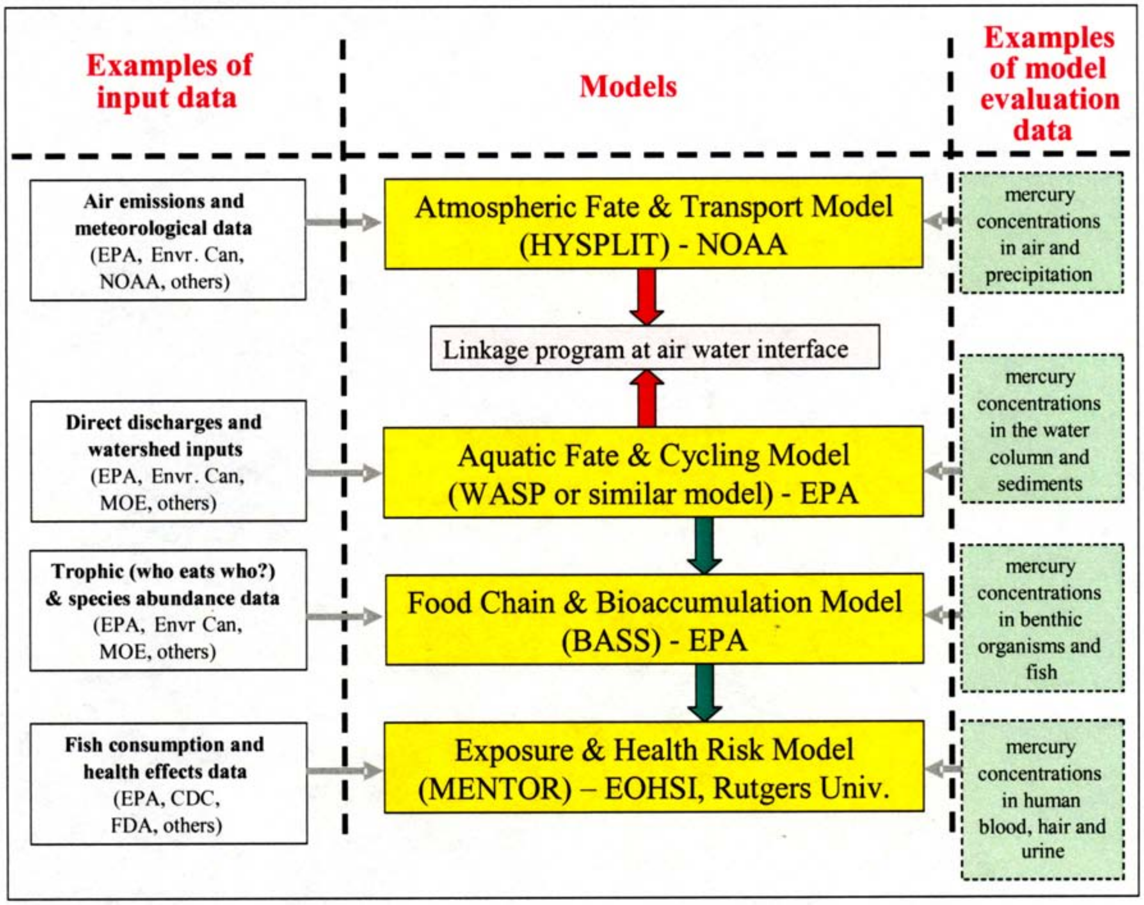


Figure 30. Overall Project Organization

Acronyms and abbreviations:

NOAA National Oceanic and Atmospheric Administration

EPA U.S. Environmental Protection Agency

EOHSI Environmental and Occupational Health Sciences Institute (Rutgers University)

Envr. Can. Environment Canada

MOE Ontario Ministry of the Environment

CDC Centers for Disease Control and Prevention

FDA U.S. Food and Drug Administration

HYSPLIT Hybrid Single Particle Lagrangian Integrated Trajectory

WASP Water Quality Analysis Simulation Program

BASS Bioaccumulation and Aquatic System Simulator

MENTOR Modeling Environment for Total Risk

In 2006 the working group and the IAQAB will host an expert workshop to consider progress in integrating these various model components. The support of the Great Lakes Water Quality Board (WQB) will be sought to secure comprehensive data on effluent, runoff, and tributary loadings of mercury. Members of the WQB and the SAB and possibly individuals involved in the management of the Oswego Area of Concern will be invited to participate in the workshop. The goal of this event is to assess progress toward a modeling scheme tracking the loadings of mercury into the waters of Lake Ontario, subsequent partitioning therein, and the resulting extent of human exposure.

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Chapter 2.2.2-Environmental Fate and Food Web Accumulation Modeling-Dr. Elsie Sunderland, Office of Research and Development, National Exposure Research Laboratory, U.S. EPA

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ANNEX 2 OF THE GREAT LAKES WATER QUALITY AGREEMENT

THE COMMISSION'S PRIORITY

Institutional difficulties have delayed the development and implementation of many Remedial Action Plans (RAPs) and lakewide management plans (LaMPs). In order to progress toward delisting Areas of Concerns the RAP and LaMP processes must be expedited, focusing efforts on achieving environmental improvements and restoring beneficial uses. Work under this priority will assist governments and RAP and LaMP implementers to identify institutional opportunities for the timely implementation of plans. The Commission committed to undertake consultations and workshops to identify challenges and highlight potential remedies.

Chapter Three presents advice from the Great Lakes Water Quality Board to the Commission regarding Annex 2.

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ANNEX 2 OF THE GREAT LAKES WATER QUALITY AGREEMENT

REPORT OF THE GREAT LAKES WATER QUALITY BOARD

Annex 2:
Keys to Implementing Remedial Action Plans

**REPORT OF THE GREAT LAKES
WATER QUALITY BOARD**

Annex 2: Keys to Implementing Remedial Action Plans

3.1 Introduction

Efforts to restore Great Lakes harbors, tributary mouths, connecting channels, and embayments officially began in 1987 with revision of the Great Lakes Water Quality Agreement. Under Annex 2, the Governments of the United States and Canada agreed to develop and implement Remedial Action Plans (RAPs) in cooperation with the state and provincial governments, and including public consultation, in designated areas where the prescribed beneficial uses of water quality were degraded.

Restoration goals in the designated Areas of Concern (AOCs) are termed delisting targets, to refer to the goal of being removed from the AOC list through successful remediation of beneficial-use impairments (BUIs). Since 1987, efforts in two AOCs - Collingwood Harbour, and Severn Sound, Ontario - have successfully restored beneficial uses resulting in their delisting. Other AOCs–Presque Isle Bay, Pennsylvania and Spanish Harbour, Ontario–are in the recovery stage signifying that all remedial actions have been taken and the focus now is on monitoring while the AOCs respond. Work in the other 39 AOCs has succeeded in restoring and even delisting individual BUIs, but the BUIs still require remedial action in the vast majority of the areas.

Despite these successes, the International Joint Commission (IJC) has expressed concern with the slow overall progress in developing and implementing cleanup and protection strategies in most AOCs. The IJC has reported on lessons learned and the status of remedial actions within AOCs in publications such as *Beacons of Light - Successful Strategies Towards Restoration in Areas of Concern* and *The Status of Restoration Activities in the Great Lakes Areas of Concern,* as well as in specific status reports for the St. Lawrence River, Niagara River, Hamilton Harbour, St. Marys River, and Detroit River.

The Great Lakes Water Quality Board (WQB), as principal advisor to the IJC, held two consultations with RAP coordinators and RAP implementation group representatives to discuss RAP implementation issues. One consultation was held in Romulus, Michigan in March 2003 with RAP practitioners from the Clinton, Detroit, and Rouge river AOCs. The second consultation occurred in June 2004 in Toronto, Ontario with representatives of Canadian RAPs from the Bay of Quinte, Detroit River, Hamilton Harbour, and Toronto Region AOCs.

The objectives of these consultations were to:

- Learn how RAP successes to date had been achieved;
- Become informed about key AOC issues;
- Become informed about factors that inhibit progress; and
- Ascertain how the WQB could help advance RAP implementation and the restoration and protection of AOCs.

The WQB received candid perspectives from individuals faced with the day-to-day challenges of implementing RAPs. These representatives provided the WQB with a historic perspective of how their RAP and advisory committee or similar group evolved. Many RAP activities and groups began with a great deal of excitement and energy, which dissipated as time passed and issues grew increasingly complex and expensive.

3.2 Remedial Action Plan Implementation Strategies

Two distinct strategies for RAP implementation emerged from the consultations. In **centralized** RAPs, the RAP is the core program that integrates ongoing remedial and monitoring work, and combines different environmental programs and projects as RAP activities. In **decentralized** RAPs, the RAP is one of many watershed programs or other planning activities. Each approach has strengths and weaknesses.

In AOCs that incorporate RAP activities into other planning initiatives, it can be difficult to garner support due to limited recognition of the RAP and its goals. However, the time, effort, and resources that would have been invested to promote the RAP can be focused instead on remedial activities. In this strategy, the overall goal of a clean, healthy environment is supported though other planning initiatives in which the RAP is an element, but specific RAP goals are not directly promoted. Issues of accountability and responsibility for RAP implementation are thus more difficult to identify in decentralized RAPs.

In AOCs where the RAP is centralized and is the tool used to bind activities together, citizens and local politicians can readily identify with the plan's goals and support its activities. Accountability and responsibility are clear; however, time, effort and resources must continually be devoted and applied to promote the RAP and its activities as a distinct program.

3.3 Remedial Action Plan Issues and Themes

At the two consultations, representatives shared successes and challenges experienced with each RAP. While each had unique aspects, many issues were fundamentally the same. These similarities, however, do not translate into a prescribed "one shoe fits all" approach to restoring AOCs. Indeed, each RAP must be developed with its respective community characteristics and goals in mind in order to determine the best approaches to implement remedial activities.

In March 1998, the IJC released a special report to the governments entitled *Beacons of Light - Successful Strategies Towards Restoration in Areas of Concern*. Similar to the RAP consultations, the report discussed common problems and major obstacles to RAP implementation. The major obstacles included:

- Lack of planning for implementation of "big ticket" remedial measures;
- Reduction in government support with no associated increase in local capacity;
- Failure to set priorities within and between AOCs;
- Inadequate input and attention from the public;
- Not getting information into the hands of doers, movers, and shakers; and
- Failure to quantity benefits of remediation, particularly regarding human health.

See http://www.ijc.org/php/publications/html/beacon/beacon.html for more details.

These six obstacles were discussed during the WQB's consultations. Although progress towards restoring ecosystem health has been made, these obstacles persist. The discussion can be broadly summarized into two main categories essential to the success of RAPs and for the restoration of AOCs:

- The science (research and monitoring) involved; and
- Leadership and accountability.

Following is a summary of the discussion between the WQB and RAP practitioners.

> Many AOCs, especially those that are geographically small or distant from scientific institutions, have received little attention by the scientific community. As a result, these RAP practitioners must search for technical assistance.

3.3.1 The Science

Beneficial Use Impairments and Delisting Targets

Since the inclusion of 14 beneficial-use impairments (BUIs) in the Agreement, RAP practitioners have been working to determine what scientific investigations are needed to sufficiently document whether specific BUIs are still impaired, and what monitoring or assessment studies are required to demonstrate response to remedial measures and whether beneficial uses have been restored. Many AOCs, especially those that are geographically small or distant from scientific institutions, have received little attention by the scientific community. As a result, these RAP practitioners must search for technical assistance. Communication between RAP practitioners from different AOCs can help, but comparisons between AOCs must be made with caution because of ecosystem complexity. For example, several AOCs may have the same impaired beneficial uses, but the root causes of the impairment may not be the same. An impairment of degraded benthos (organisms living at the bottom of a body of water) could range from contaminated sediment (a historical legacy) to excess sediment entering the water body (an active sediment source). In addition to understanding the cause of impairment and how it impacts the beneficial use, each RAP team needs to understand the ecological (physical, chemical, and biological) characteristics of their ecosystem in order to determine the goals of restoration and the remedial measures most promising to achieve them.

The general AOC listing/delisting guidelines for BUIs developed by the WQB and published by the IJC in 1991 do not include specific measurable numeric targets. Consequently, at the consultations RAP practitioners identified quantitative delisting targets as a high priority. While the process for developing delisting targets varies, a number of RAP groups have benefited greatly from government or academic scientists who are committed on a personal level because they live or work in the area, and bring technical knowledge to assist with the development of delisting targets.

The WQB and RAP practitioners engaged in a lengthy discussion regarding the usefulness and applicability of BUIs and the establishment of delisting targets. BUIs are intended to be "indicators" of healthy environmental conditions; thus, should BUIs be broadened to more directly include issues of sustainability and human health? The RAP practitioners cautioned the WQB to ensure the BUIs and the RAP process did not lose their focus on water quality, and they still consider the current BUIs relevant and good gauges of ecosystem health. Considering the amount of time, effort, and resources devoted to determining their status in AOCs and establishing delisting targets, these BUIs should be retained during the upcoming Agreement review. However, the practitioners also recognize the need to address the restoration of AOCs more holistically. Better definitions are needed for specific achievable goals (delisting targets) to allow those implementing remedial actions to more readily show progress towards delisting the AOC.

In cases where the community felt it necessary, additional goals and targets such as sustainability and water conservation have been developed. This illustrates the flexibility and ingenuity of the RAP process as local communities determine the environmental conditions that they are willing to live with, and adopt a plan that potentially (and ideally) is supported by all levels of government.

That said, several RAP practitioners felt that some issues, in particular human health, should be the responsibility of federal governments and other relevant agencies. They believe these agencies have the resources to examine such complex issues and take the appropriate - and often costly - actions.

The involvement of the health community in most RAPs is limited. The WQB considers the Agreement's language sufficient to involve the health community, and their involvement could assist in articulating the public-health benefits of cleaning up an AOC. Involving the health community would also connect different government agencies to the RAP process and further strengthen the resolve to clean up AOCs more quickly.

While RAP practitioners and the WQB agreed that BUIs and a RAP's associated goals, or delisting targets, are sufficient to engage the public, translating the science into terms which are meaningful for the broader public is necessary in order to gain public support for RAP projects. People judge the health of the environment by whether they can swim in the water, drink the water, and eat the fish, which are covered by the current BUIs in Annex 2. The public also needs to understand the implications of RAP actions including the health impacts, the costs of cleanup, and the benefits of restoration.

The RAP practitioners felt that better communication of the science to the public is needed.

Several practitioners noted that RAPs can become outdated, and the scientific rationale used to evaluate BUIs and determine delisting targets may need to be re-evaluated after a certain amount of time. Accountability and timelines may also require updating. RAP groups undertaking this step consider it valuable, for it reaffirms agency and community commitment to RAP goals as well as provides an opportunity to document successes in remediation and resulting improvements in ecological and economic conditions in the AOC.

Monitoring

Monitoring is essential to the RAP process. Consistent, appropriate, and long-term monitoring is necessary to determine if remedial actions are improving environmental conditions within the AOC. In Project Quinte, a database on microbial monitoring has been maintained by scientists from different agencies since 1972 and has proven very valuable to that AOC.

The RAP practitioners emphasized the need for improved and more frequent monitoring. This is particularly important at bathing beaches, which are often closed based on limited sampling. This sends a message to the public that the environment is in poor condition, which may not be an accurate interpretation.

Different RAP groups are able to capitalize on different monitoring programs. Similar to the development of delisting targets, having agency scientists or academics who live or work in the AOC is extremely beneficial to the RAP. Unfortunately many monitoring and research programs are tied to an individual's work and if that individual moves on the monitoring program may be lost.

Within an AOC, practitioners often have to rely on different government agencies and other groups to conduct monitoring. Monitoring methods may not be consistent, making data comparison challenging. Ensuring adequate geographic coverage of the AOC can also be challenging.

Most RAP groups are adaptable and have learned the benefits of having various groups conduct monitoring. For example, within the Hamilton Harbour AOC, a high school teacher and his students regularly conduct stream monitoring and invite local media, which helps raise the profile of RAP issues in local news. This provides an opportunity for the RAP to be promoted, for the public to be educated about the RAP, and provides data to describe environmental conditions of the harbour.

The involvement of the health community in most RAPs is limited. The WQB considers the Agreement's language sufficient to involve the health community, and their involvement could assist in articulating the public-health benefits of cleaning up an AOC. Involving the health community would also connect different government agencies to the RAP process and further strengthen the resolve to clean up AOCs more quickly.

3.3.2 Leadership and Accountability

Ownership of the Remedial Action Plan

In AOCs, the issue of leadership and accountability can be perplexing. Most groups the WQB spoke with consider the development of a RAP a community-based, stakeholder approach. This means that community "buy in" and support for activities is fundamental to the success of the RAP process. Local community support is necessary because many cleanup activities are implemented at a local level; however, the ultimate responsibility for ensuring cleanup rests with the federal, state, or provincial governments. This can and often does lead to complications. Assigning leadership and accountability to the RAP process is difficult, because it is a process that must be built on cooperation and mutual assistance. All levels of government and the public are necessary components to the success of the RAP and, at various levels; all must accept the responsibility of leadership and accountability.

Federal support often must be matched and/or additional funds sought in order to maintain RAP coordination and implementation functions. The need to continually seek funds detracts from efforts to implement remedial actions. Increasingly, RAP groups are recognizing that, in addition to implementing remedial actions, they must find ways to promote behavior-changing activities within the broader public. One key example is gathering support for increased water taxes for improvements to wastewater infrastructure. Promoting behavior-changing activities generates support for RAP goals and also helps to educate the public that their individual actions do impact the environment. As RAP groups prepare to undertake large-scale remediation projects, it is becoming obvious how important these efforts to educate the public about the environmental and human-health benefits of implementing costly projects are to RAP success.

Leadership can change over time and the same agency or group does not necessarily have to maintain the leadership role. This can depend on the phase (*e.g.,* planning or implementation) and type of remedial activity (*e.g.*, habitat creation or sediment remediation) the RAP is undertaking. Some RAP groups are preparing a statement of clarity to determine who is accountable for which aspects of the RAP, and assign responsibility and confirm commitment to complete the project.

Because of the nature of its consultations, the WQB was fortunate to meet with well-established local RAP representatives. However, the WQB is aware that such representatives are not found in all AOCs. Each RAP group indicated that strong local leadership is critical for developing and implementing the RAP. An individual contact person is needed for each RAP who also involves the broader public in the process. The RAP coordinator position can be difficult to sustain without stable funding.

The complexities of establishing and maintaining leadership in binational AOCs is often even more challenging. RAP practitioners suggested that the IJC could play a valuable role in bringing these AOCs together and strengthen their communication, in particular those binational areas working on independent or separate RAPs.

Involvement of Local Government

It can be problematic for the federal, state, or provincial governments to lead certain remedial actions because those activities are considered within local (*i.e.*, municipal, county) jurisdiction. All RAP groups represented at the consultations recognized the importance of gaining local government support. Inviting public dignitaries to events also attracts the media, and the presence of both increases the public profile of RAP activities. Additionally, local politicians are often the key to obtaining funds necessary for large-scale restoration. The support and involvement of the public works, pollution control, and parks and recreation departments is invaluable to the RAP process.

Most AOCs incorporate several different jurisdictions thus increasing the complexity of gaining political support. With several different jurisdictions involved, it can be difficult to reach consensus on commitment levels, responsibilities, priorities, and appropriate remedial actions. In particular, it can be challenging to involve the local governments upstream of the AOC and RAP groups will need assistance to engage those governments through policies, funding mechanisms, or communication opportunities. Without this help, it is difficult to provide incentives for upstream communities to fund a project that more directly benefits people living outside their community.

Many of the RAP groups at the consultation were successful in getting several RAP goals, or statements pertaining to the RAP, incorporated into the official plans of relevant municipalities. This identified commitment can then be used to leverage actions and funds.

3.4 Recommendations

A coordinator is essential for the implementation of Remedial Action Plans. To help improve accountability, the coordinator must be responsible for reporting progress, problems, and resource needs. The Water Quality Board recommends to the International Joint Commission that:

- **Governments identify a Remedial Action Plan coordinator for each Area of Concern at the state, provincial, and/or local level and provide funding to support the position.**

The Water Quality Board also recommends to the International Joint Commission that:

- **Governments provide stable funding for monitoring the appropriate parameters to show progress toward the restoration of beneficial uses.**
- **The Commission help raise the profile of Remedial Action Plans.**

Arranging site visits for Commissioners in Area of Concern communities is one mechanism to get local politicians and the media out to meet, greet, and discuss the issues.

The Water Quality Board further recommends to the International Joint Commission that:

- **The Commission help coordinate meetings and workshops to bring together for mutual education representatives from Areas of Concern, including binational Areas of Concern, dealing with similar issues.**
- **The Commission encourage and foster the science necessary to assist Remedial Action Plan groups with the development of delisting criteria.**

3.5 Acknowledgements

The WQB thanks RAP coordinators and public advisory council chairs who met with the Board to share their knowledge, perspectives and comments regarding implementation of their RAPs.

URBANIZATION

THE COMMISSION'S PRIORITY

Throughout North America, the trend over the past 20 to 30 years has been toward greater urbanization with its related increase in hard, impervious surfaces. This trend is accelerating and producing profound negative effects on local ecosystems throughout North America. Some local, regional, and state/provincial governments have embraced tools, such as watershed planning, urban-growth boundaries, and conservation design to lessen the impacts of urbanization.

The Commission addresses those elements of urbanization that impact water quality in the Great Lakes basin, and transfers information and knowledge to decision makers. Specifically, it considers the linkages among land use, unplanned growth, shoreline hardening, and altered hydrologic regimes, as well as implications for transportation and air quality. Also considered are elements of a renewed effort related to the former reference given to the Commission in 1972 regarding pollution from land-use activities. The potential for climate change to exacerbate water-quality impacts in urban centres is also considered.

Chapter Four presents advice and insight from the Great Lakes Science Advisory Board to the Commission regarding urbanization.

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Chapter Four

URBANIZATION

REPORT OF THE GREAT LAKES SCIENCE ADVISORY BOARD

Urban Land Use

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Urban Land Use

4.1 Summary

International Joint Commission (IJC) interest in land-use issues dates back to the seminal Pollution from Land Use Activities Reference Group's (PLUARG) mid-1970s studies, which linked land-use practices to water-quality degradation. During the 2003-2005 priority cycle, the Science Advisory Board's (SAB) Work Group on Parties Implementation reviewed stormwater best management practices and developed a computer simulation of an Ontario watershed to evaluate current and historical water quality and quantity conditions.

Urban areas discharge water via storm sewers, treated sewage outfalls, and sanitary/combined sewer overflows. These discharges must be managed in an integrated fashion because all three contain pollutants that can damage human health and the natural environment. The most common form of stormwater treatment is diversion to a constructed pond or wetland. However, concerns about low treatment efficiency have prompted the investigation of alternative approaches, many of which aim to restore infiltration patterns and streamflow levels to predevelopment conditions.

The results of the computer simulation to evaluate the impacts of alternative urban forms and stormwater management options clearly demonstrate that urbanization has radically changed both water quantity and quality, and that flow alterations in the headwater areas of a watershed are more significant than those in central watershed areas. As a result of these studies and where site conditions permit, compact urban form coupled with low-impact development stormwater control measures appear to be the preferred approach for managing urban stormwater in the Great Lakes basin. In areas not suited to low-impact development measures, infiltration-based wet-pond systems are a reasonable choice.

4.2 Introduction and Background

Concern with land-use impacts on the Great Lakes system is central to the Great Lakes Water Quality Agreement under Article VI and Annex 13. Specifically, Annex 13 "delineates programs and measures for the abatement and reduction on non-point sources of pollution from land-use activities." IJC interest in this issue dates back to the PLUARG studies that linked land-use practices to water quality degradation. Urban land-use effects on Great Lakes water quality were explicitly addressed in the Commission's tenth and twelfth biennial reports, which included recommendations designed to evaluate and mitigate water-quality degradation from urban sources.

In its *1997-1999 Priorities Report*, the SAB emphasized the need for special attention to nonpoint pollution issues related to urbanizing areas in the basin. The SAB further noted in its *2001-2003 Priorities Report* that the trend toward urbanization is accelerating in the basin and adverse impacts are increasingly apparent.

Other Great Lakes agencies, jurisdictions, and groups have likewise expressed concern about impaired water quality resulting from land-use activities in the basin. For example, in June 2003, the Great Lakes - St. Lawrence Mayors' Association passed a resolution entitled, *Promoting Environmental Quality and Economic Prosperity through Sustainable Land Use Practices*. Their resolution noted that coastal communities have a vested interest in sustainable land-use practices that restore and protect water quality and they are, therefore, interested in advancing sustainable land-use practices, including "smart growth" initiatives. The mayors called for a binational initiative involving municipal officials that would characterize the urban land-use problem, document the environmental and economic benefits of sustainable land-use practices, and present case studies of innovative best management practices (BMPs) that communities could adopt.

During the 2003-2005 priority cycle, the Work Group on Parties Implementation was again tasked with providing advice on the urban land-use priority. To accomplish this assignment, the Work Group embarked on an ambitious work plan which included organizing and participating in several workshops. The Work Group also undertook collaborative initiatives with university researchers and government agencies to assess BMPs, evaluate U.S. and Canadian government programs and policies related to urbanization in the basin, and provide watershed-based, urban-form scenario modeling as a guide to local, regional, state/provincial, and federal governments on developments that are more protective of the quality of receiving waters.

Specifically, the Work Group undertook the following:

- A commentary on post-PLUARG progress on urban and (to a lesser extent) agricultural land-use issues;
- A review of the extensive literature regarding the types and effectiveness of stormwater BMPs, involving review of approximately 120 studies of the 22 most common conventional and low-impact development (LID) practices, including the City of Toronto's July 2003 survey of available stormwater management practices;
- Computer simulation of an Ontario watershed to evaluate hourly flow and water quality conditions before development, in 1971, in 2004 (the status quo), and assessing several different combinations of urban form and stormwater management practices using the 2004 population;
- An assessment of some of the recently revised State of the Lakes Ecosystem Conference (SOLEC) suite of land-use indicators; and
- Parallel U.S. and Canadian studies of regulatory and institutional frameworks for urban land-use management, with explicit analysis of the current and potential role for senior federal and state/provincial governments.

Eliminating the pollutant source is always the first priority BMP. Municipalities throughout the region have recently enacted ordinances and bylaws to achieve this goal and protect receiving water quality: Dayton, Ohio has banned road salt; Madison, Wisconsin has banned the sale and use of phosphorus-containing fertilizer; several Canadian cities, including Toronto, have enacted laws on cosmetic pesticide use; and some jurisdictions have implemented sewer-use regulations and programs to retrofit water meters in older residential areas.

Eliminating the pollutant source is always the first priority BMP. Municipalities throughout the region have recently enacted ordinances and bylaws to achieve this goal and protect receiving water quality: Dayton, Ohio has banned road salt; Madison, Wisconsin has banned the sale and use of phosphorus-containing fertilizer; several Canadian cities, including Toronto, have enacted laws on cosmetic pesticide use; and some jurisdictions have implemented sewer-use regulations and programs to retrofit water meters in older residential areas.

Findings and results are reported below with pertinent recommendations to the IJC. A collaborative IJC-SAB urbanization priority is anticipated in the 2005-2007 priority cycle.

4.3 Urbanization Pressures on Great Lakes Water Quality: A Post-PLUARG Review

On November 8-9, 2004, the Work Group on Parties Implementation participated in a workshop sponsored by the Great Lakes Commission. This workshop reflected on the IJC's PLUARG activities of the 1970s and considered possible lessons for understanding and addressing nonpoint source pollution challenges facing the Great Lakes today. The speakers included individuals who held leadership roles in PLUARG. They suggested that PLUARG represented a unique opportunity and experience and would be difficult to replicate.

PLUARG focused on large-lake functions and nonpoint loading dynamics, especially the importance of storm events, with an emphasis on agricultural nonpoint sources of pollution. It produced hundreds of technical reports, a clear set of recommendations, and specific load-reduction targets for phosphorus. Although it achieved scientific success and broadened perspectives among disciplines, post-PLUARG progress was modest. Only a few of its recommendations were implemented. Momentum diminished as other elements of national environmental agendas competed for attention. The solutions depended too much on state/provincial and local resources, which were less amenable to targeting than federal resources. Some argue that resources were not sufficiently focused on the highest-priority problems. For example, an emphasis on phosphorus reduction coupled with a lack of clarity about expected outcomes allowed governments to emphasize reductions of phosphorus in municipal waste streams and avoid the more difficult challenge of confronting nonpoint sources.

Progress continues today on technology and strategies for phosphorus management. The increase in concentrated animal feeding operations (CAFOs) in the basin is a major concern, primarily because of their potential as sources of excess nutrients. These concerns are expected to intensify with global climate change and associated uncertainty about hydrology, water demand, and water-column processes.

Finally, regulatory delays slowed the replacement of old pesticides, like atrazine, by more benign substitutes.

In the future, the lakes will be increasingly valued, point-source controls will continue to improve, and CAFOs will increase in number. Geographic information system (GIS) technology has improved greatly the capability to inventory, model, and analyze spatial pollution dynamics, but much needs to be learned about the role of pharmaceuticals and other "emerging" pollutants.

Strategies for identifying and addressing the most serious of pollution that have been developed for agricultural nonpoint sources have not come nearly as far with respect to urban sources. At the watershed level, environmental and urban planning goals remain unclear — whether to intensify settlement in already developed urban areas in order to maximize unstressed land or to expand the developed area by mixing green space with settled areas to spread out the impacts.

4.4 Effectiveness of Conventional Stormwater Best Management Practices

Urban areas discharge water to streams, rivers, wetlands, and lakes by three main flow routes: stormwater channels (storm sewers); outfall discharge from municipal wastewater treatment plants; and overflows from the collection system conveying water to municipal wastewater plants (sanitary/combined sewer overflows). These are intimately interlinked and must be managed in an integrated fashion. All three contain pollutants that can damage human health and the natural environment.

In 1999, Environment Canada produced an updated assessment of the impacts of municipal wastewater on receiving waters and human health. The assessment listed consequences of the release of inadequately treated wastewater (Environment Canada, 1999):

- Restrictions on recreational water uses (*e.g.*, beach closures);
- Restrictions on fish and shellfish consumption;
- Nutrient enrichment leading to eutrophication or undesirable algal growth;
- Degradation of aesthetics;
- Restrictions on drinking-water consumption;
- Isolated and rare cases of waterborne disease caused by sewage contamination of drinking-water supplies;
- Added costs to agricultural, industrial and municipal users for treatment of unacceptable water;
- Degradation of fish and wildlife habitat with reduced aquatic and wildlife populations, and thermal enhancement/increased temperatures; and
- Depletion of dissolved oxygen.

Problems in the Great Lakes created or accentuated by the discharge of waterborne pollutants from urban areas have been recognized by many agencies, including the IJC (*e.g.*, IJC 1978; 1987; 2001; 2003). The U.S. Environmental Protection Agency (EPA) ranked urban runoff as the second largest source of impairment of lakes and estuaries in the United States, and the third largest source of impairment of rivers (Lee and Jones-Lee, 1994).

In response to these concerns, many technologies have been used to achieve water-quality objectives. If sufficient funds were available to purchase and operate appropriate technology, such as distillation or membrane filtration, it would be possible to treat stormwater to drinking water standards. Due to the extent of the stormwater management problem in North America, however, such treatment is almost never implemented. Many municipalities do not even perform routine maintenance of stormwater management facilities. While most cities do employ some form of stormwater management, these measures are rarely if ever coordinated across a watershed or even subwatershed area, and some may have unintended negative impacts on the environment.

The principal obstacles to effective stormwater management are lack of money and the lack of a regional infrastructure planning and coordination mechanism.

As a basis for the computer simulation work described below, the Work Group commissioned a literature review in early 2005 to assess current thinking on the effectiveness of conventional stormwater BMPs. This work was conducted by Dr. Hugh Whiteley of the School of Engineering, University of Guelph, and Christine Zimmer, a graduate student under his direction. This work builds on an earlier survey of BMPs compiled by the City of Toronto, focusing on recent scholarly literature on the performance of the 22 most commonly used BMPs.

The review demonstrated that, in contrast to the very long history of operation of water treatment technologies designed to produce potable water and treat municipal and industrial wastewaters, urban stormwater treatment is a much more recent phenomenon. Tsihrintzis and Hamid (1997) identify the mid-1980s as the time when urban stormwater pollution emerged as a recognized major contributor to impairment of receiving waters in the United States, and the same is generally true in Canada.

The principal obstacles to effective stormwater management are lack of money and the lack of a regional infrastructure planning and coordination mechanism.

Concern about urban stormwater is justified by the large loads of pollution that it can convey. Compared to runoff from forested land, Schueler and Caraco (2001) estimate that stormwater runoff from industrial and commercial development can carry ten times the amount of phosphorus, five to eight times the amount of nitrogen, four times the amount of suspended solids, and 60 times the bacterial load. The chemical content and the size distribution of suspended sediments also differ from rural

to urban settings. Zanders (2005) found that gutter sediments along urban streets accumulate over extended periods and are predominantly coarse particles, and finer particles, with their associated organic and inorganic pollutants, are washed into storm sewers. In a rural or forested setting, most of these small particles are trapped in small depressions in the land surface and only a relatively small proportion leave the site (Zanders 2005).

Automobiles, trucks, and busses contribute additional pollutants to stormwater, including leaked fluids, by-products of combustion, and high concentrations of zinc and copper from brake and tire wear (Zanders 2005). Even roofs are sources of stormwater pollution. Although many studies have shown that runoff from house roofs contains low concentrations of most pollutants, some have shown that roof runoff can contain high concentrations of metals, such as copper and lead, possibly arising from deterioration of roofing or drain materials (*e.g.*, Bennerstedt 2002; Zobrist *et al.* 2000). Nevertheless, other studies have determined that roof runoff is of sufficiently high quality and suitable for groundwater recharge; see *e.g.*, Whiteley *et al.* (1993); Chocat *et al.* (2001); and Burnham (2004).

These findings provide important constraints on the treatment options available for urban stormwater. The most obvious approach to treatment is to convey it to an existing wastewater treatment plant. However, because of the high flow rates and the large volume of runoff that can occur during a storm event, it is very uncommon for a wastewater treatment plant to have the hydraulic and treatment capacity to process the large quantity of stormwater that flows off pavement and roofs. In Canada and the U.S., the most common form of stormwater treatment is diversion to a constructed pond or wetland in which stormwater can be detained and suspended sediment deposited. Toxicological studies of those sediments (*e.g.*, van Loon *et al.* 2000; Chocat *et al.* 2001; Marsalek *et al.* 2002) found some significant potential risks and demonstrate that metal leaching can occur to a depth of 1.5 meters below an infiltration basin in an industrial catchment.

Stormwater ponds and wetlands do not provide a consistent level of treatment. Although removal efficiencies of up to 80 percent of suspended solids (lower for other pollutants) are possible with ponds, actual treatment efficiency is often far lower. In part, this is because of inadequate cleaning and maintenance regimes. Furthermore, ponds and wetlands are not designed to remove certain kinds of pollutants. For example, stormwater BMPs have some capability to reduce microbial transfer to receiving water, but results are highly variable (Stinson and Perdek 2004). Disinfection by chlorination or ultra-violet treatment, while rare, has been demonstrated to be feasible and effective in removing pathogens.

Concerns about low treatment efficiency, sediment toxicity, and poor removal of bacteria and viruses have prompted the investigation of alternative approaches. These approaches mainly focus on reducing stormwater runoff by retention and infiltration of stormwater onsite. Many of these aim to restore infiltration patterns and streamflow levels to predevelopment conditions by creating increased opportunities for percolation of rainwater into soils. Examples of such options include bio-retention cells (depressed areas planted with native vegetation and equipped with an under-drain); rain gardens (depressed garden areas without an under-drain); rain barrels (to collect rainwater for onsite use); roof-leader disconnects (to direct roof runoff to onsite infiltration rather than to storm sewers); roof gardens; and various forms of porous pavement. However, these measures must be used with care to avoid transferring pollutants to groundwater. This requires site-by-site analysis and site-specific monitoring data, neither of which are readily available in Canadian or U.S. municipalities. Onsite stormwater management options must also be carefully sized to obtain the desired results; see the discussion below of computer simulation results.

4.5 Computer Simulation of Alternative Urban Forms and Stormwater Management Options

As earlier Work Group reports have demonstrated, it is very difficult to obtain high-quality empirical data on the relative impacts of different urban forms. The implications of a given form may also vary depending on its location within a particular basin, and the degree to which conventional or alternative stormwater treatment options accompany it.

In 2004, the Work Group commissioned a computer simulation study to evaluate the impacts of alternative urban forms and stormwater management options within Schneider Creek, a small watershed in Kitchener, Ontario. This work was funded by the Ontario Ministry of the Environment using its Canada-Ontario Agreement funds and was conducted by Water's Edge Environmental Solutions Team Inc., in conjunction with Harold Schroeter and Associates and Dr. Hugh Whiteley and Christine Zimmer, authors of the BMP literature review presented above.

Schneider Creek was selected because it is a rapidly urbanizing watershed with a long period of continuous-flow monitoring. The watershed also has good soils data (important for the evaluation of alternative stormwater management techniques), and it discharges to the Grand River, a major Lake Erie tributary, thus allowing evaluation of potential changes in flow and pollutant loading to the Great Lakes.

The study compiled and used historical flow and anecdotal records to reconstruct three watershed conditions:

- Predevelopment conditions that would have existed in the late 19th century (1871 was selected for reference, which is 100 years before the first collection of formal flow records), with cropped land, pasture and woodlots;
- 1971 (early urbanization) conditions, when formal flow monitoring began in the basin; and
- Current basin population and development configuration.

Using the predevelopment condition as a baseline, the consultants superimposed five hypothetical development scenarios designed to mitigate or reverse the undesirable water resources impacts of urban development on the basin:

Scenario 1: A small number of wet ponds in place (current condition).

Scenario 2: Maximum implementation of stormwater detention ponds (2004 Full Wet Ponds).

Scenario 3: Current development patterns with partial implementation of low-impact development practices.

Scenario 4: Maximum implementation of low-impact development practices (2004 Maximum Low-impact Development) that could be retrofitted in existing development, although not necessarily maximum size of individual practices.

Scenario 5: Hypothetical high-density urban development land use coupled with maximum implementation of wet ponds (2004 High Density Plus Wet Ponds).

Low-impact development (LID) is an urban development design concept to facilitate the restoration and/or improvement of a stream's hydrological regime to a predevelopment state, thereby reducing nonpoint source pollutant loads and improving receiving stream water quality, while preserving the natural ecological integrity of the watershed (Coffman 2001).

The Guelph All Weather Sequential Events Runoff model (GAWSER) was selected to evaluate the relative performance of these land-use scenarios on streamflow and water quality. GAWSER is a deterministic model that can be used either as an event-based (that is, simulation of a single rain storm) or as a real-time continuous (that is, realistic hour-by-hour simulation over years or decades) simulation model. The continuous-simulation capability of GAWSER was particularly important. Event simulation does not provide adequate assessment of the cumulative effects of sustained wet or dry weather; continuous simulation provides a more realistic picture of how the watershed would respond to realistic weather sequences across all seasons.

GAWSER is a physically based, continuous-in-time model that generates overland flow and recharge to groundwater from a set of hydrological-response units that represent various combinations of soil type and surface treatment (including a unit for connected impermeable area). Infiltration is modelled using the Green-Ampt representation and recharge is an outflow from soilwater storage. Properties of soilwater storage such as soil depth and percolation rates are set from topographic location, surficial geological characteristics, and soil type. Meteorological inputs to the model include hourly data on precipitation and temperature. Based on these inputs and calculated water movements, the model produces hourly predictions of the quantities of water stored in surface depressions, soil, water, and groundwater; rates of overland flow at subwatershed outlets; and streamflow. On an hourly basis, the model also calculates the dry-weather accumulation of pollutants on the land surface, and any wet-weather washoff and transport of pollutants into receiving waters. Both rainfall and snowfall are incorporated in the simulations. The model simulates any continuous period of time for which there is reasonably continuous hourly data. In the present case, the period of simulation was approximately 40 years simulated hourly. The general features of the GAWSER model are similar to the modelling procedures used successfully by Villarreal *et al.* (2004) to assess stormwater BMPs in an inner-city setting. Additional details on GAWSER are available in Schroeder *et al.* (2000a; 2000b; and 2003).

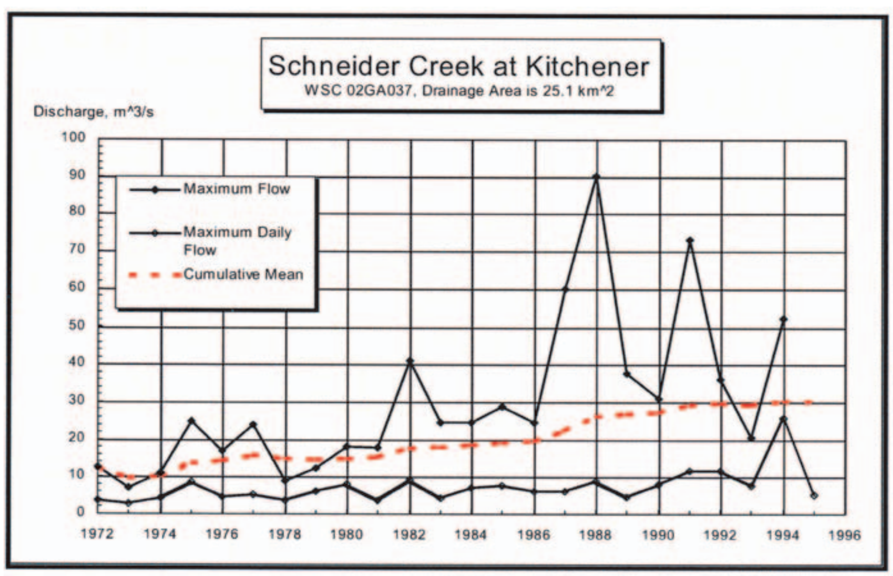

Figure 1. Effect of Urbanization of the Watershed from 1972 to 1996

The results of the GAWSER simulations, combined with analysis of historical records, demonstrated that urbanization has radically changed both the quantity and quality of water leaving the Schneider Creek watershed (Figure 1). These findings confirm those of many other studies: because cities have a high proportion of roofed and paved surfaces, less rainwater is able to infiltrate the land surface naturally, and more runs off hard surfaces into receiving waters.

In the study watershed, the estimated predevelopment (1871) monthly distribution of flows, the mean May-to-October peak flows, and the seven-day low flows from 1871 were very different from those observed in 1971, when recordkeeping began, and from today. Generally speaking, the monthly flow volumes during the winter and early spring (January to April) remain unchanged, but the flows during the summer and early autumn are noticeably higher today compared to predevelopment conditions. Indeed, current May-to-October mean peak flows have doubled in all parts of the watershed, clearly reflecting the influence of higher imperviousness and increased diversion of rainwater directly into streams. At the same time, urbanization has caused the mean seven-day low flows to be reduced in all parts of the watershed, with the greatest reductions occurring in the headwater areas. This is because headwater areas are where most groundwater recharge occurs. Development in headwater areas must, therefore, be planned and managed carefully to avoid damage to the recharge function and thus to all downstream hydrologic processes.

Urban form has diverse implications for the environment, including not only the type and quantity of pollutants generated, but also where those pollutants are discharged in the watershed and what treatment measures are feasible. In addition, urban form has implications for transportation, the area and cost of land required (and therefore on land use types such as agriculture displaced by urbanization), and the capital and operating costs to maintain that development.

The results revealed that alternative forms of urban development and stormwater control are capable of reducing some undesirable changes in streamflow and reducing the pollutant loadings that accompany urban development. However, the scenarios differed somewhat in their implications for water resources (Figures 2 and 3). In simple terms, the target of restoration efforts is to bring peak flows *down* to predevelopment levels, and low flows *up* to predevelopment levels.

The following summarizes the results for the three scenarios judged to be most effective for stormwater management. Figure 2 shows that the full wet ponds scenario (Scenario 2) was the most successful in controlling peak flows, closely followed by the high density plus wet ponds scenario (Scenario 5). This is not surprising because wet ponds are expressly designed to control peak flows. The maximum LID scenario (Scenario 4) did reduce peak flows, but not to the level of the other two scenarios.

Figure 3 shows that the maximum LID (Scenario 4) was most effective at raising low flows to predevelopment conditions (and beyond). By contrast, the high density plus wet ponds scenario appears to decrease low flows, an undesirable outcome.

The main differences among the scenarios are summarized as follows.

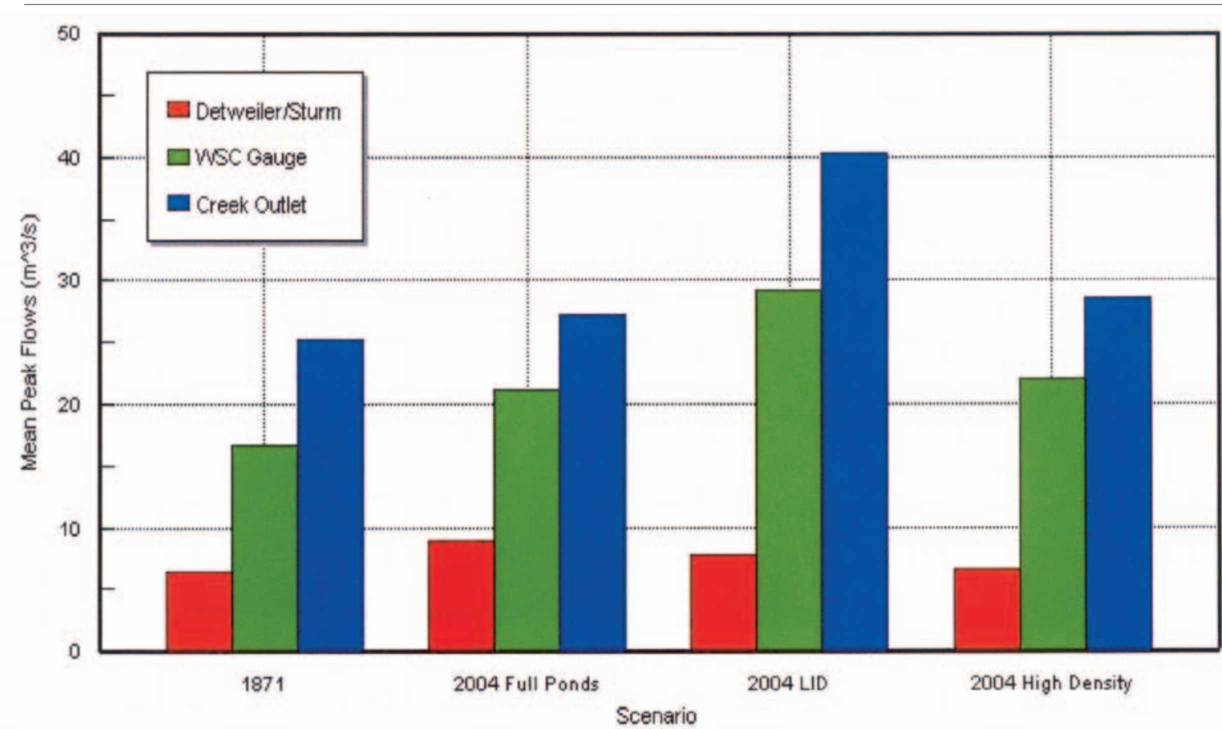

Figure 2. **Comparison of May-to-October Peak Flows**

4.5.1 2004 Full Wet Ponds Scenario 2

This scenario simulated the impact under 2004 conditions of installing as many stormwater detention ponds as possible in the study watershed, achieving the following results:

- Excellent reduction of peak flows to predevelopment levels;
- Good reduction of sediment load; and
- Fair success in raising low flows, but not to predevelopment levels.

4.5.2 Maximum LID Scenario 4

This scenario evaluated the impact under 2004 conditions of maximum implementation of LID technologies throughout the basin, but not installation of any additional stormwater detention ponds. The scenario therefore evaluated the change possible using mainly LID approaches in the future. Achieving these results would require extensive changes to street and building layouts, and the feasibility of individual technologies would be depend on the availability of adequate subsoil water movement and adequate depth to groundwater. However, the simulation results suggest that maximum implementation of LID technologies could achieve the following:

- Excellent match to pre-urban flow pattern;
- Poor control of highest summer flows (could be improved by enlarging LID facilities);
- Excellent restoration of low flows to pre-urban levels;
- Total streamflow and evapotranspiration patterns a close match to pre-urban conditions;
- Fair reduction of sediment loading (could be improved by enlarging LID facilities); and
- Overall best fit to flow rate patterns and overall water balance.

4.5.3 High Density Plus Wet Ponds Scenario 5

This scenario tested whether it is better to concentrate development in smaller areas intermixed with green space. This scenario assumed very high density development in some basin locations, and the maximum possible number of stormwater detention ponds throughout the basin (but not LID approaches). Simulation results indicated that this approach would have the following results:

- Very good reduction of peak flows to predevelopment levels;
- Less vehicle use and thus less generation of air pollutants.
- Good control of sediment loadings;
- Failed to replicate the pre-urban pattern of moderately high flows;
- Poor restoration of low flows;
- Seven-day low flows, while adequate in volume, would be warmer than natural in summer;

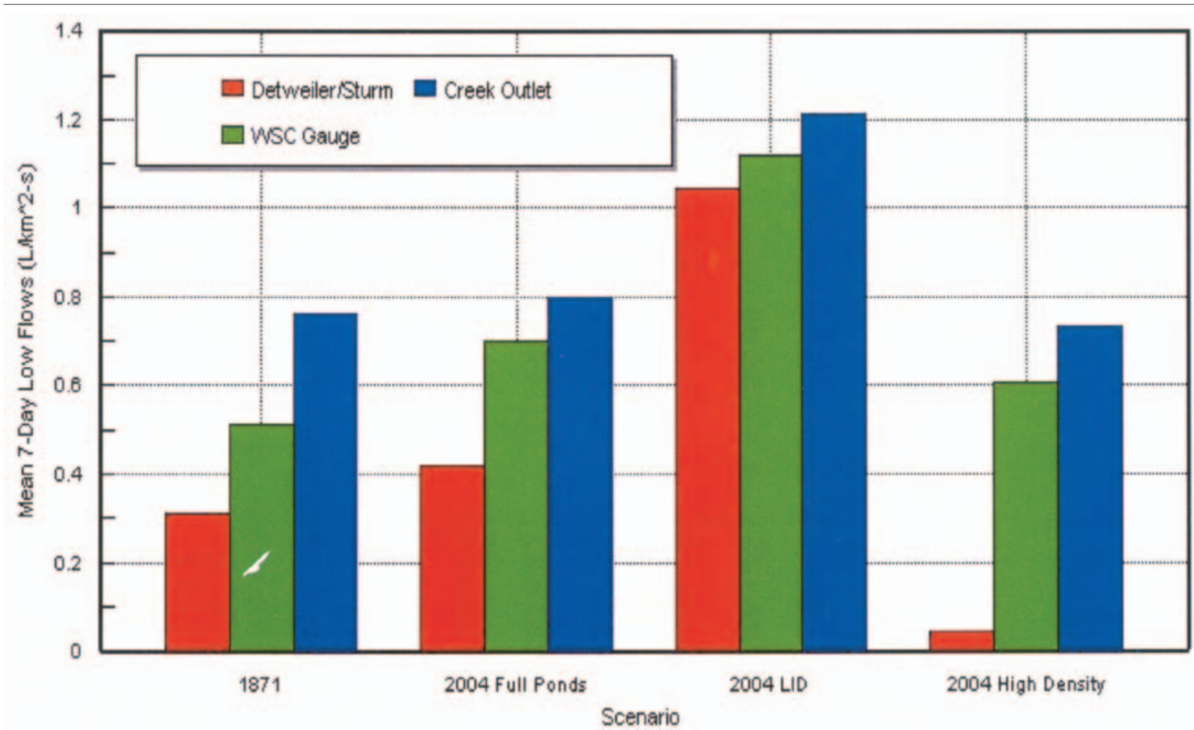

Figure 3. Comparison of Mean 7-Day May-to-October Low Flows

- Allowed runoff to be concentrated in small areas for effective treatment; and
- Could be difficult to find suitable locations for ponds because of need for large land area.

The simulations also demonstrated that actions in the headwater areas of a watershed are more effective than those in central watershed areas. In the centre of a watershed, several tributary streams may enter the main channel. In a large rainfall event, each tributary experiences a sharp increase in flow and each conveys that increased flow to the main channel more or less simultaneously. Unless all tributaries are equally well controlled, the impact of the combined streamflow peaks may be very difficult to reduce. Headwater areas are often characterized by smaller, more sensitive streams, yet the impacts of changes in headwater areas can be important for all downstream river reaches.

Finally, these results strongly emphasize the importance of local topography, soils and hydrogeology in assessing the feasibility of urban form and stormwater management strategies within a watershed.

In summary, based on the result of the studies, and where site conditions permit, compact urban form coupled with low-impact development stormwater control measures appears to be the preferred approach for managing urban stormwater in the Great Lakes basin. In areas not suited to low-impact development measures, infiltration-based wet-pond systems are a reasonable choice.

4.5.4 Recommendations

The SAB recommends to the IJC that:

- **The Commission, in cooperation with the Parties, state/provincial, municipal, and other regional stakeholders, convene a binational conference to elucidate the extensive data and experience available on the causes of, and potential solutions for, water resource impacts of urbanization in the Great Lakes basin.**

A significant body of research exists on the environmental impacts of urbanization, but this is not easily accessible to planning practitioners and land-use decision makers. The IJC could serve as, or establish, a coordinating body to bring the best scientists on this topic together with the people and agencies that will use their findings in the field. Findings from this conference could also serve as the basis for development of a manual of practice for use at the local level. This goal is best accomplished through a single binational conference, perhaps co-sponsored by senior federal and state/provincial governments and foundations.

The SAB recommends to the IJC that:

- **The Commission urge the Parties, in partnership with state/provincial and local governments, and as a principal outcome of the proposed binational conference, to develop detailed technical guidance for local governments on how to evaluate the suitability of a site for specific recharge-based stormwater management measures.**

While considerable watershed-level planning and evaluation is underway throughout the basin, local governments usually have little expertise in evaluating site-specific soil and groundwater conditions. Without specific technical guidance, they may not be able to determine BMPs for a given site. Such decisions are especially critical in urbanizing headwater areas where groundwater/surface water interaction commonly occurs.

Scientific debate is best suited to a single large conference; however, dissemination of detailed guidance should occur at the local level. A series of regional educational workshops is envisioned (possibly creditable toward professional practice hours for municipal engineers and planners). At these workshops, the guidelines and their underlying scientific principles would be explained and case histories of successful applications within the region presented.

One of the largest problems confronting municipalities is a lack of understanding about development strategies that also protect the environment. The manual of practice referred to above could assist in meeting this need. However, there is also an important link between land-use decision making and infrastructure funding, which should be explicit in senior government policy.

The SAB recommends to the IJC that:

- **The Commission encourage the Parties to make infrastructure funding contingent on the existence of adequate watershed management and land-use planning processes, including an integrated, cost-effective plan for management of sewage treatment plant outflows, sanitary/combined sewer overflows, and stormwater discharges.**

Funding for urban infrastructure should not flow to municipalities unless acceptable comprehensive, land-use plans are in place. Funding priority should go to plans developed and implemented jointly over a watershed or multi-municipal area. In the U.S., the Federal Interagency Task Force might be an appropriate mechanism to make funding available to state and regional authorities that wish to develop joint or regional growth-management plans. In Canada, the Canada-Ontario Agreement could provide a framework for such an arrangement.

4.6 Workshop on State of the Lakes Ecosystem Conference (SOLEC) Land-Use Indicators

In previous reports, the SAB has commented on proposed State of the Lakes Ecosystem Conference (SOLEC) land-use indicators. A focus of these comments has been the potential difficulty of their implementation. Recently, SOLEC revised these indicators and sought feedback.

On October 8, 2004, the Work Group on Parties Implementation hosted a workshop in Toronto in association with SOLEC. The first half of the workshop provided an opportunity for retrospective and prospective reviews of work being done under the IJC's urban land-use priority. The second half was devoted to discussions about some of the proposed SOLEC urban/suburban land-use indicators. SOLEC organizers received a report of the workshop proceedings to help guide them in refining the indicators.

A number of interesting points were raised in response to the presentations and during discussion. Workshop participants expressed the view that ecosystem impacts are important, so the current SOLEC and IJC focus on the water-quality impacts of urbanization may be too narrow to address all ecosystem goals. In addition, participants emphasized the need to address the "human drivers" of urbanization—for instance, why so many people seem to prefer low-density housing—in the management of water quality impacts.

Workshop participants suggested several new indicators including: releases from combined sewer overflows in cities that have such systems; a general "state of the infrastructure" indicator (perhaps based on the age and condition of water and sewer infrastructure); and indicators of the human-health aspects of urbanization.

Participants offered the following comments on the four current SOLEC land-use impact indicators most clearly connected to the SAB's current work.

4.6.1 Urban Density (SOLEC Indicator #7000)

Participants urged caution in the use of the word "sprawl," which has negative connotations. They observed that the impacts of a given urban form depend on its design and possibly its location in the watershed. In addition, consideration of density alone ignores patterns of development, some of which may have less impact than others. For example, brownfield development may be preferable to greenfield development. On the other hand, greenfield development may incorporate state-of-the-art low impact features that may be less feasible for infill projects in existing urban areas. Finally, participants argued that it is important to track trends in density, because the potential impacts of an older urban area that is losing population may be significantly different from those of a newer, growing urban area.

A peer-review session of the SOLEC indicators held in January 2004 recognized that the term "density" is ambiguous and recommended dividing the urban-density indicator into two separate indicators. One indicator would reflect density of development and redevelopment in designated metropolitan areas, and the other would reflect density of development and redevelopment outside those areas (SOLEC 2004).

4.6.2 Vehicle Distance Traveled (SOLEC Indicator #7064)

Workshop participants questioned the value of this indicator and suggested that measures of time spent in vehicles or amount of fuel consumed might be more closely related to environmental impacts. For example, in the Greater Toronto Area, commuting times are expected to increase by 300 percent and carbon dioxide emissions per capita by 42 percent over the next 27 years (Neptis Foundation 2002). The number of people traveling in vehicles and the type of vehicles are also important considerations.

4.6.3 Ground Surface Hardening (SOLEC Indicator #7054)

Participants observed that ground-surface hardening can be difficult to measure accurately, although improvements in remote-sensing technology may make this easier in the future. In addition, some emerging BMPs, for instance porous pavement, appear to be of intermediate perviousness and may need to be separately distinguished in inventories of impervious surfaces.

4.6.4 Brownfield Redevelopment (SOLEC Indicator #7006)

Brownfield sites are a major challenge for inner cities on both sides of the border, but also a major opportunity for redevelopment and urban infill. In the context of land-use planning, brownfield development can help alleviate pressure on the urban fringe while taking advantage of existing infrastructure. However, participants emphasized the financial implications of brownfield development. Developers are often hesitant to embark on such development because of liability concerns and associated cleanup costs.

4.7 Legal and Institutional Strategies

Previous priorities reports have identified legal and institutional arrangements as central to controlling the impacts of urbanization on the Great Lakes. In the current cycle, the Work Group commissioned two reports, one from each country, to evaluate institutional opportunities and obstacles for the control of land use and its impacts.

4.7.1 United States

Professors Elizabeth Brabec and Peter Kumble of the Department of Landscape Architecture and Environmental Planning, Utah State University, prepared a paper to identify the most effective tools and techniques for controlling water-quality impacts from urban growth, and how the IJC might support federal and state governments to enable effective use of these tools. They began with a literature review of the impacts of urbanization on water systems and found that most studies equate urbanization with imperviousness, although different types of urban land uses actually create different amounts of impervious cover (Brabec *et al.* 2002). They further noted that there may be large variations of imperviousness within the same type of land use or land cover as well as with increasing lot size. Impervious cover for residential land use, for example, typically decreases with increasing lot size, but increases per capita on a watershed level due to the increased road length required to access each site (Brabec and Kumble, 2005). The authors suggest that the role of unconnected impervious areas, which direct runoff to adjacent pervious land rather than to storm sewers, is significant in determining water quality impacts and is not adequately reflected in most methodologies used to determine impervious cover. Brabec and Kumble also cite a study by Schueler as widely increasing acceptance of the claim that water quality declines when impervious surfaces cover at least 10-15 percent of the land area (Schueler 1995).

Brabec and Kumble state that government efforts focusing on engineering BMPs are a misplaced priority. They believe that the real priority should be on watershed-level planning for stormwater management, for which engineering solutions are implementation tools (Richardson *et al.* 2003). They further note that hydrologic models, to be valuable in helping to reduce impacts from impervious cover, need to be used in the land-use decision-making process, but they observe that this is rarely the case. The impacts of impervious land uses on water quality can vary depending on the location of impervious cover within the watershed, such as proximity to stream channels or storm sewers (Weaver and Garman, 1994; Allan *et al.* 1997; Johnson and Gage, 1997; Wang *et al.* 2001). These findings are consistent with those from the computer simulation study discussed above and should also be considered in the context of the SOLEC indicator on ground-surface hardening (#7054) discussed above. Brabec and Kumble further note that land use and vegetation cover are the only variables affected by impervious cover that humans can control, underscoring the importance of factoring these variables into the land-use planning process (Harbor 1994).

"... land use planning is a local initiative and decision makers are not oriented towards thinking ... regionally, beyond the limits of their jurisdiction."

The authors evaluate different BMPs based on the type of degradation each is intended to address (*e.g.*, stream hydrology, channel morphology, water quality) and describe the appropriate planning response for BMP implementation. Brabec and Kumble suggest that mature forests be used as a baseline for planning adequate filtration within a watershed. They also note that the choice of BMPs within a planning area necessarily depends on the watershed goals and resources to be protected, and, more importantly, how the BMPs individually and collectively affect the impact of watershed development. This also is consistent with the findings of the computer simulation study described above, which emphasized the need for site-specific evaluation of BMP feasibility and performance.

In Brabec and Kumble's view, the key to effective BMP implementation — to ensure that they are indeed best practices — is their strategic application as part of a regional growth-management strategy. Such a strategy directs new development to occur in the least sensitive areas of the watershed, and protects mature forests and other open spaces to provide the natural infrastructure to ensure that ecosystem functions remain intact. The greatest impediment to the regional-planning approach, note Brabec and Kumble, is that "land use planning is a local initiative and decision makers are not oriented towards thinking ... regionally, beyond the limits of their jurisdiction." They observe that nonstructural BMPs, such as tradeable permits and mitigation banking, could have particular promise for regional growth management.

Brabec and Kumble conclude that the greatest opportunities for reducing the impacts of development on the watershed relate to land- and watershed planning. They identified "home rule," where land use decision-making is delegated to the smallest local units of government, as a particular obstacle to regional watershed management and planning initiatives. Citing recent reports from the U.S. General Accounting Office that detail the lack of coordination among current and future environmental strategies, Brabec and Kumble emphasize that the federal government can assist by providing leadership through legislation and funding that enables coordination among current and future environmental strategies. The U.S. Great Lakes Interagency Task Force, established by Presidential Executive Order in May 2004, is an important example of how the federal government can provide leadership. However, this task force lacks a land-use mandate and focus, and its charge to protect the Great Lakes seems inconsistent with the President's proposed cuts in grants to local communities in the Great Lakes.

4.7.2 Canada

Professor Marcia Valiante of the Faculty of Law, University of Windsor, prepared a report on institutional and legal mechanisms for the management of urbanization impacts in Ontario. She observes that southern Ontario has been subject to significant growth in population and land development. The pattern of new development has been largely to expand onto agricultural land in the regions around Toronto by building low-density residential communities; 75 percent of all new Ontario housing starts in 2001 were of this type (Federation of Canadian Municipalities 2005). In addition, beyond areas served by public transit, commercial development has occurred in a scattered and uncoordinated fashion. This has led to concerns about increased automobile use (as a result of development that requires car travel); increased impervious cover, rising infrastructure costs, loss of agricultural land and natural heritage features, and associated adverse environmental impacts.

Valiante notes that the current pattern of development in southern Ontario is the result of a complex interaction of institutional factors. All levels of government influence development patterns through regulations, the tax system, economic measures, and information-based measures. As a result, the present system provides inconsistent direction with some factors encouraging and others discouraging sprawl. Furthermore, while planning decisions are made largely at the local level by municipal governments, other levels of government may become involved in various ways and for various reasons. For example, the provincial government provides land-use planning policy guidance through the Provincial Policy Statement. Under the Canadian Constitution, land-use planning responsibility is vested in the provincial government, but actually is delegated to the municipal level. The province therefore has the responsibility to grant approval of certain decisions and hears appeals of municipal decisions at a provincial tribunal (the Ontario Municipal Board).

Regional governments (so-called "upper tier" municipalities) may also become involved in land-use planning. Local decisions must conform to the plans of regional governments (where there is a two-tier structure) and some decisions must be approved by the regional government (*e.g.*, amendments to the municipality's Official Plan and subdivision plans). Conservation authorities, which report to the Ontario Ministry of Natural Resources but are charged with management of water and forest resources at a regional or watershed level, can also provide guidance and approval on certain issues affecting water bodies. Finally, the federal government may be involved where federal lands or concerns are affected, for example in the management of important natural fisheries, international waterways, First Nations' lands, or similar concerns.

Tax measures and the availability of grants and other financing tools provide important incentives and disincentives for particular development locations and building choices. These economic and tax measures are currently used by the federal, provincial and local governments to promote seemingly inconsistent growth-management objectives.

Valiante states that existing planning tools give municipalities the ability to limit sprawl (*e.g.*, regional plans, the Provincial Policy Statement, community improvement plans, and development charges), but these have not generally been successful. A consensus is emerging from all levels of government that fundamental changes are needed in the existing system in order to accommodate expected population growth on the Canadian side of the Great Lakes basin (estimated at an additional four million people by 2020) in a way that will have less environmental impact. There are signs that this change has already begun. In late 2004, the Ontario government began to implement significant changes in planning regulations that will affect development patterns through regional growth management, particularly in the regions around Toronto. The federal government has identified urban issues as a priority national concern and, to that end, has begun providing significant financial support to upgrade municipal infrastructure. The Martin government in its 2005 budget also made a commitment to direct a share of the federal gasoline tax to municipalities, and has taken other actions to expand funding sources. This new funding should temper some of the development pressure on municipalities; however, more sustained and coordinated measures are needed to facilitate long-term growth-management strategies.

Valiante concludes that more action is needed at all levels to ensure consistency in policies and measures, coordination across existing institutions, and leadership.

The findings of the Brabec and Kumble and the Valiante reports agree in several key ways. On both sides of the border, the day-to-day business of land-use planning should and will continue to rest with local governments. However, this planning should be subject to regional or state/provincial regulatory frameworks that require consistency of practice and coordination across a planning region and consider impacts on water resources. As Ontario has recently demonstrated, regional planning targets could also be set by state/provincial governments and delegated to local governments for implementation. Both reports emphasize the need for public involvement in the planning process as an important education and implementation mechanism, and, therefore, as a means of building social capacity for making sound land-use planning decisions.

State/provincial governments also have a responsibility to ensure adequate oversight of local planning processes and decisions. For state/provincial and federal governments, a key lever for this oversight is available through funding mechanisms, which could incorporate requirements for watershed-level planning and a higher level of accountability for impacts to water resources than currently exists.

4.7.3 Recommendations

The SAB recommends to the IJC that:

- **The Commission urge the Parties, through state/provincial agencies as appropriate, to direct agencies that have local planning expertise and responsibility to initiate institutional coordination to limit urban/suburban/exurban development to shared watershed areas where stormwater best management practices and low-impact development can be successfully implemented.**

In the U.S., appropriate mechanisms are metropolitan and regional planning organizations and regional stormwater management authorities. In Ontario, there is a bewildering array of local planning instruments (such as Official Plans and perhaps source-protection plans), and provincial policy statements and instruments. Coordination among these is essential and cannot be left to local governments. Rather, it must occur at the provincial level, integrated with federal and provincial infrastructure funding.

Finally, financial institutions have a critical, but often overlooked, influence on how urban and other land-use decisions are made. Private development in particular depends on financing from commercial institutions. Those institutions can drive development decisions at least as much as government bodies. Education of such institutions as to the environmental implications of urban development may, therefore, be beneficial.

Because almost all land-use development projects involve funding from some kind of financial institution, those institutions have a great deal of influence over the early decision-making process. If developers cannot obtain adequate funding for projects with certain features that would be advantageous environmentally (*e.g.*, innovative designs, unusual locations), such projects would not be proposed. Financial institutions may have funding criteria that unwittingly discourage land-use practices that would be advantageous environmentally, while still making good business sense. The IJC could address this situation by providing information on environmentally sound land-use practices in the Great Lakes basin to those institutions responsible for funding development. This outreach could take many forms, including conferences aimed at sharing information in both directions (*i.e.*, constraints faced by institutions and practices that make environmental sense), educational information tailored for financial institutions (*e.g.*, brochures, websites), or even certain requirements for institutions handling public funds.

The SAB recommends to the IJC that:

- **The Commission initiate dialogue involving the Commission, Parties, developers, and financial institutions to explore the environmental implications of urban land-use financing decisions.**

One opportunity to engage these groups in dialogue would be through a session at the major conference proposed in the first recommendation above.

4.8 Conclusions

On the basis of this work, the SAB concludes that land use in urban and urbanizing areas has a significant impact on natural flow regimes and water quality. To some extent, those impacts can be reduced or reversed by careful land-use planning coupled with site-appropriate stormwater-management infrastructure. Our results suggest that, where site conditions permit, compact urban form coupled with low-impact development stormwater control measures may be the preferred approach for managing urban stormwater in the Great Lakes basin. In areas not suited to low-impact development measures, infiltration-based wet-pond systems are a reasonable choice.

Furthermore, our studies indicate that actions in the headwater areas of a watershed have more impact than those in central watershed areas. If those actions create adverse impacts downstream, those impacts are more pronounced and more difficult to reverse than similar actions in central watershed or downstream reaches. The other side of this coin is that, protective measures undertaken in headwater regions, such as protection of important groundwater recharge zones, have far greater beneficial impact on downstream systems than similar actions taken farther downstream.

While these results are preliminary and should be confirmed with additional research, they strongly reinforce the need for thoughtful, integrated planning of land use and urban infrastructure, especially in headwater areas. Senior governments have two important roles in this regard. First, they can provide policy leadership and educational outreach to local governments. Second, through their critical role as funders, they can and should tie infrastructure funding to the existence of adequate integrated land-use and infrastructure plans.

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Chapter Five

HUMAN HEALTH

THE COMMISSION'S PRIORITY

New risk factors to human health from waterborne pathogens, such as newly identified sensitive populations, global transportation, antibiotic resistance, and wastewater treatment efficiency, have created a heightened awareness of the importance of new scientific knowledge in managing these risks. In addition, several new or relatively unknown classes of chemicals are emerging as potential water pollutants in the Great Lakes basin. These include polybrominated diphenyl ethers (such as fire retardants), various pharmaceuticals and personal care products, and approximately 20 currently used pesticides that are a potential concern for human and ecosystem health.

The Commission's scientific assessment identifies priorities for future research and data needs. It also considers the policy implications of establishing action levels to protect human health based on multi-media exposure and the interactive effects of toxic substances including PCBs, mercury, and the substances noted above. Where information is unknown or incomplete, the relevance of the precautionary principle must be considered.

Chapter Five presents advice and insight from the Great Lakes Science Advisory Board to the Commission regarding human health.

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HUMAN HEALTH

REPORT OF THE GREAT LAKES SCIENCE ADVISORY BOARD

Waterborne Microbial Pathogens in the Great Lakes

5.1 Summary

Waterborne diseases still pose a threat to human health in the Great Lakes basin. Infection outbreaks and deaths in Milwaukee, Wisconsin in 1993 and Walkerton, Ontario in 2000 illustrate the threat from contaminated drinking water. Microbial pathogens can adversely impact contact recreation, such as swimming, and represent a continuing human health and economic threat. Untreated or partially treated sewage discharged to waterways is the most obvious route of potential exposure, but nonpoint source pollution is also a vehicle for microbial contamination. Pathogens from livestock, wildlife, and humans can be carried by agricultural and urban runoff. A comprehensive management approach is needed to address and minimize the risks from waterborne pathogens. The Hazard Analysis and Critical Control Point (HACCP) system is widely used as a food and water safety management tool. An Environmental Pathogens Strategy modeled on the Binational Toxics Strategy is proposed for adoption in the Great Lakes basin.

5.2 Introduction

The Work Group on Ecosystem Health reviewed scientific knowledge on waterborne microbial pathogens in the Great Lakes region. The Work Group prepared background reports and invited expert papers that discussed societal influences on microbial pathogens, monitoring of pathogens, and management tools.

Diseases such as typhoid and cholera are no longer major problems in the Great Lakes basin. However, outbreaks and deaths in Milwaukee, Wisconsin in 1993 and Walkerton, Ontario in 2000 illustrate that waterborne microbial pathogens still pose a threat to human health. These pathogens are generally transmitted by the fecal-to-oral route in which people are exposed when they ingest or come into contact with water contaminated with human or animal feces. Although attention and management efforts have focused on treating water and wastewater to prevent microbial contamination, human activities continue to contribute directly and indirectly to contamination of surface and groundwater. For example, contaminated water used for irrigating crops can contribute to human illness following ingestion of raw unwashed foodstuffs such as lettuce and other vegetables. Irrigation increases agricultural production, but the water returned to aquatic systems is often contaminated with nutrients and pathogens.

To manage microbial contamination, pathogens must be monitored in the environment and their transport and fate understood. In the early 1900s, the Commission undertook a bacteriological monitoring study that examined cross-boundary pollution. That study was revolutionary in its day, and remains relevant to current monitoring programs. New technologies and approaches can determine the presence of pathogens and provide information on their fate in the environment. The Global Ocean Observation System (GOOS), which tracks harmful algal blooms, can be used as a model for tracking waterborne pathogens in the Great Lakes. It could provide managers with accurate, real-time information on microbial contamination and help to determine if beach advisories should be issued. HACCP planning could provide a framework for a comprehensive plan to manage microbial contamination in the Great Lakes basin.

Despite the increase in the number of disease outbreaks due to waterborne pathogens since the late 1990s, many people drink and recreate in Great Lakes basin water without any thought of microbial pathogens. In the U.S., the Centers for Disease Control and Prevention (CDC) estimates that waterborne pathogens cause 300,000 infections per year. The largest event in U.S. history occurred in Milwaukee, Wisconsin in 1993, when 400,000 people became ill and 100 died due to *Cryptosporidium* contamination of the drinking water supply. Outbreaks have also occurred in Canada, most notably in Walkerton, Ontario in 2000 when seven people died as a result of drinking water supply contamination.

Microbial pathogens also pose a risk for contact recreation. In 1996, beaches in Great Lakes states were closed 3,700 times. Globally, the cost of human disease caused by sewage pollution of coastal waters is estimated at four million lost "man-years" annually, which is roughly equivalent to an annual economic loss of approximately $16 billion U.S. For one Lake Michigan beach, net economic losses due to beach closures were estimated to range from about $1,200 to $37,000 per day, depending on value assumptions (Rabinovici *et al.* 2004).

Greater awareness of microbial pathogen issues is occurring because of the increase in size of sensitive populations, the existence of global transportation networks that spread pathogens worldwide, antibiotic resistance, and zoonotic transmission. New findings suggest that pathogens may be linked to diseases such as hardening of the arteries (Ismail *et al.* 1999). Chemical and microbial contamination may interact to exacerbate effects. Improved estimates of land-based inputs and models of water-circulation patterns and water quality are needed to reduce risks of human exposure, provide data and information for more effective control of anthropogenic inputs, and maximize recreational income (Cheves 2003).

5.3 Microbial Pathogens

Human activities have introduced many microbial pathogens that are not native to water bodies (National Research Council 2004). Few studies exist on the ecology and evolution of microbial pathogens in comparison to research investigating pathogenicity. In order to gain a real understanding of the pathogens' abundance, distribution, and fate in the environment, it is vital to understand their autecology and indicators.

The National Research Council (2004) identified five critical questions for studying pathogens:

1. What is the distribution and abundance of pathogens? Are the reservoirs for the pathogen biotic or abiotic?
2. What are the fates of freshwater pathogens in coastal or marine waters?
3. Is the residence time of a pathogen sufficient to allow genetic exchange or change to occur?
4. What biotic and abiotic factors influence the viability and survivability of waterborne pathogens? Are there environmental conditions that promote genetic exchange or the acquisition of genetic elements that confer selective advantage under clinical conditions?
5. What effect do sampling and environmental variations have on the efficacy of indicators?

Pathogens of concern include bacteria, toxic algae, protozoa, and viruses, which are briefly described below.

5.3.1 Waterborne Microbial Pathogens

Bacterial pathogens such as *Escherichia coli* (*E. coli*), *Campylobacter*, *Salmonella sp.*, and *Shigella sp.* can be divided into two groups: native and introduced (National Research Council 2004). In aquatic systems, pathogenic bacteria are a small component of a diverse microbial community. Some can form endospores, specialized cells with no metabolic activity that can survive extended periods of time in harsh conditions. Other bacteria are found exclusively in humans, such as *Shigella*, whereas still others have multiple animal hosts. Bacteria with multiple hosts can transmit from one host to another. For example, *Campylobacter* is found in a wide range of mammalian and avian hosts and is a major cause of bacterial diarrheal illness in developing countries. It was also present in the drinking water during the Walkerton outbreak.

Campylobacter caused 16 cases of illness on South Bass Island, Ohio where from July 23 to September 12, 2004 a total of 1,450 cases of gastrointestinal illness were reported (Ohio Department of Health 2005). During the outbreak, nine cases of illness due to norovirus, three due to *Giardia* species, and one due to *Salmonella typhimurium* were also reported. The main source of pathogens was widespread contamination of groundwater, and several water supplies remain closed.

Campylobacter cells have a variety of hosts and are viable for months. Outbreaks have been associated with treated and untreated water sources. Other bacteria that have large environmental reservoirs include *Aeromonas*, *Salmonella*, and *E. coli*. Bacterial pathogens that are also widespread in aquatic systems are *Pseudomonas*, *Enterobacter*, *Acinetobacter*, *Klebsiella*, and *Stenotrophomonas*. These pathogens commonly cause outbreaks in hospitals and recreational settings, and are of particular concern because many are now resistant to antibiotics. Bacteria can share genetic information in several ways, which allows them to rapidly respond to environmental change.

Toxic algae, commonly cyanobacteria or blue-green algae, produce several toxins harmful to humans and wildlife. The most well-known is Microcystis. Concerns about harmful algal blooms (HABs) have increased over the last decade largely because of the perceived increase in the number and duration of events (Malone and Rockwell 2005). The toxins produced by these species cause finfish and shellfish poisoning, a variety of human pathologies that can lead to death, and mass mortalities of marine organisms including fish, mammals, and birds. A

... *Campylobacter* is found in a wide range of mammalian and avian hosts and is a major cause of bacterial diarrheal illness in developing countries. It was also present in the drinking water during the Walkerton outbreak.

HAB outbreak in 1987-88 closed shellfishing on more than 400 kilometers of North Carolina coastline during the peak harvesting season with economic losses estimated at $25 million (Malone and Rockwell 2005).

Protozoans are single-celled eukaryotes, some of which are obligate parasites that cause disease in humans. These pathogenic protozoans are often transmitted via the fecal-to-oral route (National Research Council 2004). The enteric protozoans of concern are *Giardia lamblia*, *Cryptosporidium parvum*, *Toxoplasma*, and *Microsporidia*. Because animals and humans are hosts to these enteric protozoans, they may be transmitted between humans and other animals (zoonotic transmission). Populations of protozoans are influenced by both density-dependent and density-independent factors (National Research Council 2004). Density-dependent factors include the population dynamics of the host, and survival and reproductive success of the parasite. Density-independent factors include abiotic ones such as temperature and climate. Parasitic protozoans form cysts or oocytes that for enteric protozoa are the only form of the parasite that can survive outside its host. *Giardia*, one of the more common enteric protozoans, is an obligate parasite that causes diarrhea and abdominal pain in infected humans. Approximately 2.8 million people are infected with *Giardia* each year worldwide in developed and developing countries (Ali and Hill 2003).

Microsporidia, which form spores rather than cysts, infect all animals and therefore have a large biotic reservoir. Thirteen species of Microsporidia are known to infect humans and two are associated with gastrointestinal disease (National Research Council 2004). Very little is known about their sources and there are minimal data on occurrence in surface waters (National Research Council 2004).

Cryptosporidium and *Toxoplasma* are obligate parasites that require a host to reproduce. *Cryptosporidium* is an intestinal parasite and *Toxoplasma* is a tissue parasite. Cryptosporidium infections are ubiquitous and up to 30 to 50 percent of the U.S. population has antibodies to *C. parvum* (Frost *et al.* 2002; Isaac-Renton *et al.* 1999). The primary host for *Toxoplasma gondii* is the domestic cat. However, oocytes have been found in fresh waters and coastal waters. Aside from humans, sea otters and marine mammals reportedly have become infected.

In addition to these protozoan obligate parasites, two free-living protozoans common in aquatic ecosystems can also cause illness: *Naegleria* is found in stagnant bodies of fresh water while *Acanthamoeba* is found in more types of aquatic environments, including ocean sediments. The mode of infection for both is introduction to the nasal passages via swimming rather than the anal-to-oral route. *Naegleria* infections can be serious and involve the central nervous system rather than the gastrointestinal system.

Viruses are obligate intracellular parasites and several are among the emerging microbial pathogens receiving increased attention. The viruses of concern as waterborne pathogens include enteroviruses, norovirus, hepatitis A and E, parvovirus, and adenoviruses. Many human viruses infect the gastrointestinal or respiratory systems. Viruses persist in the environment, are readily transmitted by water, and can persist ten years or more in groundwater. The most common indicators for microbial pathogens, fecal coliform bacteria, are generally not a good measure of risk from viral pathogens (Payment and Rose 2005).

5.3.2 Sources

Pathogens are introduced to water systems from a variety of sources, although most are related to discharge of human or animal waste into surface or groundwater. The most obvious route is the direct discharge of untreated sewage into waterways. This may result from combined sewer overflows, sanitary sewer overflows, or failing septic systems. Nonpoint sources also contribute to contamination, carrying pathogens from wildlife, livestock, or humans to water bodies via agricultural or urban runoff. Domestic cattle and sewage discharges are the primary sources of *Cryptosporidium* and *Giardia* (National Research Council 2004). Birds and their droppings and wildlife also contribute to the contamination of aquatic environments. Tile drainage and irrigation systems can have major impacts on receiving water quality. Pharmaceuticals are a growing concern in institutional septic systems, and raw septage (hauled sewage) is commonly spread on farmland that may be tile drained. Ballast water and holding tank releases are also a source of pathogens.

5.3.3 Methods of Detection and Monitoring

Indicators, rather than the pathogens themselves, are commonly used to monitor for microbial pathogens because they are easier and less costly to sample and, in many cases, standard methods have been developed for their measurement. Important biological characteristics of indicator organisms have been identified (National Research Council 2004):

- Correlated to health risk
- Similar (or greater) survival to pathogens
- Similar (or greater) transport to pathogens
- Present in greater numbers than pathogens
- Specific to a fecal source or identifiable as to source of origin.

Coliforms are the most common type of indicator. Many communities use fecal coliforms, or *E. coli,* as an indicator of human fecal contamination. *Enterococci* are also used because they are of fecal origin and have been strongly correlated with gastrointestinal illness from contact recreation (National Research Council 2004). *Clostridium*, a spore-forming bacterium, is a potential indicator for protozoan parasites such as *Giardia* and *Cryptosporidium* because the spores of *Clostridium* may behave similar to oocytes or cysts of the protozoans

(National Research Council 2004). Bacteriophages—viruses that infect bacteria—are used as indicators of viral pathogens.

The use of indicators is complex. The relationship between the indicator organisms used and health risks is poorly developed. The indicator's use assumes that these occur at a constant ratio with the pathogens, but this is not always valid (National Research Council 2004). Indicators and pathogens also vary in space and time, complicating sampling and detection of the organisms. Payment and Rose (2005) illustrate the difficulties with indicators with the example of *Helicobacter pylori*. Studies in Pennsylvania have shown that *H. pylori* were found in wells that were free of the indicator, coliform bacteria. Therefore, fecal coliforms are a questionable indicator for *H. pylori*. More research on pathogens and indicator organisms is required to improve detection of pathogens and understand their ecology.

Several emerging techniques and approaches are improving the ability to detect and track pathogens. Polymerase chain reaction (PCR) techniques enable researchers to identify the actual pathogens. PCR techniques can be time consuming and expensive, although new techniques such as real-time PCR have reduced the time necessary to process samples. Also, micro-arrays have been developed using genomics technology. The micro-arrays, or biochips, can immobilize up to thousands of DNA probes for waterborne pathogens. Thus there is potential to identify a variety of microbes in a water sample. However, these tools are still being developed and need to be evaluated.

5.4 Social Factors Affecting Pathogens

Sattar and Tetro (2005) discuss how social factors, such as advancements in technology, have consequences on water quality. For example, drinking-water treatment and disinfection practices drastically reduce the number of illnesses of common waterborne infections (Sargeant 2005). Other advancements discussed by Sattar and Tetro (2005) include the development of antibiotics, agricultural uses, and municipal uses.

5.4.1 Pharmaceuticals and Antibiotic Resistance

Increasingly, antibiotics are found in freshwater systems (Halling-Sorensen 1998). Until recently, nearly one in three Americans was prescribed antibiotics even though there was no valid medical reason to do so (Nyquist *et al.* 1998). Antibiotics pass through wastewater treatment facilities and are discharged to receiving waters. The presence of pharmaceuticals in these waters further promotes antibiotic resistance. Hagedorn *et al.* (1999) found bacteria resistant to antibiotics in waters that received feces from nonpoint sources. In addition, the widespread use of antimicrobial disinfectants may contribute to the problem. For example, laboratory studies with triclosan (a common active ingredient in antibiotic and antimicrobial soaps) show that bacteria that become resistant to triclosan also show resistance to antibiotics that rely on the same site of action to kill pathogens (Levy *et al.* 1999).

5.4.2 Agriculture

Agricultural runoff is a long-recognized source of pollutants to waterways; however, much attention has focused on nutrient loads into aquatic systems. Agricultural runoff also has a high microbial load, including bacteria and parasites. Sheep and cattle harbor *Campylobacter,* and the application of manure is a known source of environmental contamination (Stanley and Jones 2003). Sischo *et al.* (2000) demonstrated that water contamination with *Cryptosporidium* was positively correlated with spreading manure. A public inquiry in Canada suggested that runoff contaminated by manure may have been the cause of the North Battleford outbreak, which infected up to 7,000 people (Saskatchewan Justice 2002). Contaminated runoff was also the likely cause of the Milwaukee incident.

The concentration of animals into a small area can also adversely impact water quality (Kirkhorn 2002). A concentrated animal feeding operation (CAFO) maintains a specified number of animals within a confined area. More than 238,000 CAFOs existed in the United States in 2002, which produced 500 million tons (454 million tonnes) of manure annually. This is approximately three times greater than the waste generated by the entire U.S. population (U.S. EPA 2003). Several pathogens have been identified from the manure of CAFO animals (Guan and Holley 2003) including *Helicobacter pylori*, *Streptococcus suis*, *Brucella suis*, *Campylobacter* sp., *Yersinia enterocolitica*, *Salmonella* sp., *Listeria monocytogenes*, *Cryptosporidium parvum*, and *E. coli.*

Another pathogen that has increased in prevalence in the developed world and is linked to swine farming is the hepatitis E virus (HEV) (Clemente-Casares *et al.* 2003). HEV causes acute, self-limited, icteric hepatitis in humans and is classified as a zoonotic infection (Smith 2001) with swine acting as the main animal reservoir. HEV was once endemic only in developing countries, but it has now been identified in the sewage of many industrialized countries including Spain, France, and the United States (Kasorndorkbua *et al.* 2004).

5.4.3 Municipalities

Municipal and other human activities account for less than 15 percent of all freshwater withdrawals in the U.S. and Canada (Sattar and Tetro 2005). Through technological advancements over the last century, local governments now provide water and wastewater treatment for communities that put clean water into nearly all homes and had built a sense of confidence in the water's safety (Hrudey and Hrudey 2004). The public perception of safe water may be declining, as reflected in the increasing sales of point-of-use devices and bottled water.

As water flows from a drinking water treatment plant to the tap, the residual disinfectant levels are depleted. Biofilms, which grow within the distribution system, incorporate various opportunistic bacteria that may cause disease in susceptible individuals. *Mycobacterium avium* represents a major threat to immuno-compromised individuals (Aronson *et al.* 1999). Other potential biofilm-based bacteria include *Pseudomonas* (associated with hospital-acquired infections), *Moraxella* (ocular and respiratory infections), *Aeromonas* (urinary tract disorders), and *Legionella* (pneumonia) (Rusin *et al.* 1997; Pryor *et al.* 2004).

Three areas of waste disposal are relevant for management of pathogens: wastewater, sludge, and solid waste. Most large cities now have some form of wastewater treatment to reduce the discharge of microbial or chemical contaminants into receiving waters. For those facilities that do not use tertiary treatment, chemical pollutants that are not removed as solids are released into the environment, albeit at lower concentrations. Among the chemicals that escape treatment systems are pharmaceuticals and microbiocides.

The second waste category is sludge produced at municipal wastewater treatment plants. The use and safety of sludge is controversial because about 150 enteric pathogens may exist and thrive in sludge (Gerba and Smith 2005). Various chemical pollutants such as antimicrobials, disinfectants, and heavy metals are also present and may pose an environmental risk. Depending on the process by which sludge is converted into biosolids, microbial and organic chemical loads may decline. However, there is always a risk for heavy metal and residual contamination through either leaching or runoff. Furthermore, this risk may be heightened due to potential interactions of pathogens and irritant chemicals (Lewis *et al.* 2002). Many communities now have pretreatment programs to prevent potentially harmful chemicals from entering the municipal waste stream, thus reducing contaminant loadings to soils and receiving waters.

The third waste category is solid waste and the threat to water quality from landfills. In terms of microbial hazards from landfills, enteric viruses are unlikely to withstand the environmental conditions of a landfill (Sobsey 1978).

5.5 Monitoring Microbial Pathogens in the Great Lakes

Given their threat to aquatic ecosystems and human health, information on the presence, distribution, fate, and transport of pathogens is critical. Monitoring is essential to gain this information. The International Joint Commission (IJC) conducted a comprehensive bacteriological study in 1913-1914. That effort, although overlooked for some time, is still relevant today. By combining lessons learned from the past with current monitoring programs, traditional and new approaches can be used to increase the knowledge base required to manage microbial pathogens in the Great Lakes. The Agreement contains scarce mention of microbial pathogens.

5.5.1 Historical Monitoring: A Lesson from the Past

In the early 1900s, the IJC commissioned a landmark study to examine the extent of cross-boundary pollution in the Great Lakes. The study was limited to those areas where pollution on one side of the U.S.-Canadian border was thought to affect waters on the other (IJC 1914). Assistance was given by the U.S. Public Health Service, the Ontario and Quebec boards of health, the Michigan State Board of Health, and the New York State Department of Health. Also, many municipalities cooperated by providing information about their water and wastewater treatment practices. The study cost about $42,000, which was divided equally between the U.S. and Canada.

The study examined more than 2,000 miles of sampling transects and collected over 19,000 water samples. The study involved 17 laboratories, each of which was installed, equipped, and staffed by the IJC. A total of 1,447 locations were sampled across the Great Lakes during the summer of 1913. Investigators used methods for detecting and culturing bacteria that correspond to current techniques to determine total coliform bacteria. In addition to the bacteriological analyses, meteorological data were recorded at the sampling sites. For all the municipalities, the area, population, source of water supply, amount of water pumped, and an estimate of sewage discharge were recorded. Each municipality also reported the number of deaths due to typhoid per 100,000 people. For some cities, bacteriological analyses of domestic tap water were also conducted.

The results of the study showed extensive cross-boundary pollution in the Detroit River, Niagara River, Rainy River, St. Clair River, St. John River, lower Lake Erie, and lower Lake Ontario (IJC 1914). The major cause of this pollution was the discharge of untreated human sewage by municipalities and vessels into Great Lakes waters. The IJC recommended that "all sewage should, before being discharged into boundary waters, receive some purification treatment, and the degree of such treatment is to be determined in a large measure by the limits of safe loading of a water-purification plant." The IJC also recommended that the requirement for treatment balance concerns of public health and economics. Current treatment mirrors the approach outlined by the IJC in 1918, namely primary (mechanical) and secondary (biological) treatment of sewage (IJC 1918). The recommendations were not immediately adopted, and the scientific value of the study was limited because it was not published in the scientific literature.

Several lessons can be learned from this IJC study. One reason the study was so advanced is that it involved scientists, engineers, and public health officials across the basin. An expert panel gave serious review of the study methods and the adequacy of the research questions posed to the IJC by Canada and the U.S. The advisors promoted the use of the most technologically advanced methods. For example, bacteria samples were often grown in gel rather than agar (Durfee and Bagley 1997). Also, interested parties were given a chance to comment on the study at public hearings. The study's design and successful completion shows how input from experts and stakeholders can help to produce high-quality research. The study also shows the need to communicate findings and continue engagement with the governments to support implementation efforts.

5.5.2 Current Monitoring Efforts

The Great Lakes region has not completed another study as comprehensive as the 1913-1914 IJC assessment (Durfee and Bagley 1997). Various government agencies at all levels monitor bacteria in the basin. However, a recent complete investigation into the extent of bacterial contamination has not been conducted. Current monitoring includes drinking water and wastewater treatment facilities, and recreational beaches.

The U.S. Environmental Protection Agency (EPA) has set health goals and legal limits for total coliform levels in drinking water (EPA 2001). The total coliform rule also details the required monitoring protocol for water treatment plants, including the frequency and number of samples to collect. Wastewater treatment plants (WWTPs) or publicly owned treatment works also monitor fecal coliform. Beach monitoring programs are commonly conducted by local government health departments. These monitoring programs have the potential to provide important information regarding trends in nearshore bacterial contamination.

Bacterial contamination of public Great Lakes beaches in Canada is regularly assessed during the swimming season by public-health authorities. The authorities determine the numbers of *E. coli* or similar (fecal coliform) bacterial indicators in the waters, but their sampling and testing procedures have not been standardized (Edsall and Charlton 1997). Thus, long-term trends in bacterial indicators are difficult to identify because of inconsistencies in monitoring methods and incomplete reporting over time.

Many water quality monitoring programs in the Great Lakes basin do not include bacterial analyses. The U.S. Geological Survey's National Water Quality Assessment Program recently conducted a comprehensive study of water quality in Lake Erie and the St. Clair River (Myers *et al.* 2000), but fecal coliform bacteria were not monitored. University research programs, such as the University of Wisconsin-Milwaukee WATERbase program (UWM 2003), monitor bacterial levels, but focus on free-living bacteria and bacterial production, not pathogens. As human illness in the Great Lakes region due to waterborne contaminants became rare in the 20th century (Health Canada 1995a, 1995b, 1995c; Health and Welfare Canada 1980), management and monitoring efforts shifted to other environmental problems such as invasive species, eutrophication, and toxic sediments. Use of ecosystem-level indicators has become more popular in the Great Lakes following the start of the State of the Lakes Ecosystem Conference (SOLEC) program in 1994. In 2004 the IJC recommended that new methods to detect the actual pathogens be used rather than rely on indicators such as total coliform or *E. coli* (IJC 2004).

Water quality data are currently gathered at county and state levels, but a consistent methodology or comprehensive database does not exist, and the data are fragmented in time and space. Thus, knowledge of the extent of bacterial contamination in the Great Lakes largely is limited by a lack of consistency in monitoring, assessment, and basin-scale planning. Future efforts can learn from past and present successes and failures that show the importance of stakeholder engagement, long-term commitment, and communication in developing a successful strategy for managing bacterial pollution in the Great Lakes.

5.5.3 The Global Ocean Observation System (GOOS): A Model Monitoring Program

GOOS is a global network that collects and disseminates data and information on marine and ocean variables (Malone and Rockwell 2005). At the United Nations Conference on Environment and Development member nations ratified the Framework Convention on Climate Change and the Program of Action for Sustainable Development, which called for the creation of GOOS to enable effective management of marine systems. GOOS is based on the data and information requirements of groups that depend on oceans, thus it is a multi-user (*e.g.,* scientists, managers) and multidisciplinary (*e.g.,* chemistry, biology, oceanography) approach.

GOOS is designed to deliver relevant information to users quickly to achieve management goals and make informed decisions. GOOS is composed of:

- A monitoring network of *in situ* and remote sensing measurements;
- A data assimilation and analysis component that includes conceptual, statistical, and numerical models as well as geographic information systems (GIS); and

- A data communications component to provide rapid access to gathered information.

The Gulf of Mexico Harmful Algal Blooms Observing System (HABSOS) illustrates how such a system works (Malone and Rockwell 2005). The ultimate goal of HABSOS is to predict the probability of when and where harmful algal blooms will occur and will impact humans and fisheries. The ability to make this prediction requires, *inter alia*, information on the algal species, factors that influence blooms, and water currents. Based on observations of the forcing functions of blooms (*e.g.,* wind, flow, nutrients) and ecosystem properties, models can be developed to predict blooms based on environmental conditions.

An observing system such as GOOS could be used to monitor pathogens in the Great Lakes and to manage public beaches (Malone and Rockwell 2005). Given the current time lag between collecting a sample and laboratory analysis, a beach may stay open while it is actually unsafe, or closed after the fact. Thus, the ability to monitor and predict exposure to pathogens at beaches could improve management efforts and be more protective of threats to human health.

Such a Great Lakes observing system could use the GOOS/HABSOS model in the following way. First, basic information about the pathogens is needed to characterize their transport and fate in the environment. For example, pathogens introduced via stormwater runoff are concentrated in plumes that can be detected by remote sensing. With the new tracking techniques that are available, the movement of the plume, combined with information on the pathogens, can be used to predict the risk to bathing beaches. A regional system is being developed for southern Lake Michigan beaches (Whitman 2005).

To develop an effective Great Lakes observing system, three capabilities must be developed: more rapid detection of pathogens; timely predictions of where and when public health risks are unacceptable; and timely forecasts of trajectories and contaminated water masses in space and time. To accomplish this, more investment must be made in monitoring (*in situ* and remote sensing) and in research on pathogens. Also, the system must be sustained permanently to provide continuity and to capture the variability that characterizes the aquatic environment and the organisms inhabiting it.

5.6 Management of Microbial Pathogens

5.6.1 Current Programs

U.S. EPA has set the health goal for total coliform in drinking water at zero (EPA 2001). Water systems with coliform in more than five percent of collected samples each month fail to meet the total coliform standard, and water system operators must report the violation to the state. Positive fecal coliform tests may indicate that the system's treatment technologies are not performing properly, and actions may be needed to avoid or eliminate contamination. This may include repairing the disinfection/filtration equipment, flushing or upgrading the distribution system, and/or enacting source-water protection programs (EPA 2001). The only limit on coliform bacteria in ambient water is found in the exception to the *Surface Water Treatment Rule* (EPA 1989) to avoid filtration of surface waters, which states that total coliform bacteria should be less than 100 colony-forming units (CFU)/100 milliliters (ml) or fecal coliform should be less than 20 CFU/100 ml in 90 percent of the samples collected.

In the U.S., fecal coliform is considered a conventional pollutant under the Clean Water Act, so it is controlled through technology standards. Wastewater treatment plants must use the best available technology to minimize fecal coliform in effluent discharged to receiving waters.

Long-term trends in beach closings are difficult to interpret because of inconsistencies in monitoring methods and incomplete reporting over time. Another complicating factor is the use of varying guidelines for what triggers a beach closing. The U.S. Beach Act of 2000 requires states to adopt bacteria limits that are protective of human health as a part of their state water quality standards. U.S. EPA (2004) recently published the final rule for coastal and Great Lakes waters, which sets federal standards for ambient bacteria levels. U.S. EPA recommended a criterion of 126 /100 ml for *E. coli*, but states are allowed to use a more stringent standard. Michigan and Ohio have adopted standards as protective as the U.S. EPA criterion, and the other Great Lake states are in the process of adopting similar standards.

Ontario uses a standard of 100/100 ml whereas the national standard recommended by Environment Canada is 200/100 ml (Edsall and Charlton 1997).

5.6.2 A New Management Tool: The HACCP Approach

The Hazardous Analysis and Critical Control Point (HACCP) system is widely used in the management of food and water quality and safety (Martel *et al.* in preparation). The purpose of creating a HACCP plan is to:

- Document the major sources of risk to the end point of concern;
- Identify and implement the major means of controlling those risks in practice;
- Monitor to provide early warning of the failure of those control processes; and
- Implement corrective actions when control processes fail (Deere and Davidson 2005).

There are six basic steps in developing a HACCP plan (Deere and Davidson 2005):

- All involved in creating the HACCP must commit resources for development. Once committed, the scoping phase can begin.
- The selection of a representative to serve on the HACCP team. This calls for the identification of all users, uses, and requirements.
- Development of a conceptual model of the sources of risks and identification of possible control strategies.
- Completion of a risk assessment, including identifying the risk of water quality that is unacceptable for uses or to users, the causes (events) and hazards (contaminants), and control measures to reduce risk.
- Management planning is undertaken that identifies control loops. The loops identify the controls, monitor their effectiveness, and attempt to correct any failures based on monitoring.
- The final step is validation and verification of the HACCP. Validation determines if the scientific and technological underpinnings of the plan are valid. Verification determines if the plan is being implemented and requirements met.

Once completed and implemented, the HACCP plan provides confidence that the major risks have been identified and that ongoing, operational controls are in place to manage the risks to water quality and give early warning if water quality is likely to become impaired. The plan can be improved over time using adaptive management, as well as through expansion of its scope and the rigor of its implementation.

5.6.3 A Proposed Management Technique: An Environmental Pathogens Strategy

The Binational Toxics Strategy provides an effective mechanism to work toward the goal of virtual elimination of persistent toxic substances to protect and ensure the health and integrity of the Great Lakes basin ecosystem. A similar mechanism could provide an efficient method to address microbial contamination in the Great Lakes basin. Key components of an Environmental Pathogens Strategy include:

- Establishment of a consistent monitoring framework for pathogens across the basin;
- Promotion of the application of new technology and approaches to detect, monitor, and control microbial contamination;
- Increased employment of GIS mapping to strengthen evidence of waterborne infections;
- Investment in the creation of a water quality information database that includes microbial pathogens for the Great Lakes;
- Development and use of novel techniques, including simulation modeling, to better define the risk to human health from waterborne microbial contamination;
- Establishment of a Microbial Water Quality Network to foster collaboration among groups conducting water quality monitoring in the basin; and
- Adoption of a collaborative process by which Environment Canada and U.S. EPA—in consultation with other federal departments and agencies, Great Lakes states, the Province of Ontario, tribes, and First Nations—work in cooperation with their public and private partners to further the goals of the strategy.

5.7 Conclusions and Recommendations

The common themes among the pathogens discussed above identify research and management needs for the Great Lakes basin. Firstly, there is a need to understand the natural history and ecology of pathogens and indicators in order to better detect and manage risks to human health. Secondly, a comprehensive strategy to monitor waterborne microbial pathogens is required. This strategy should use the latest technologies and consistent methods across the basin, be maintained so that long-term data are collected, and be readily accessible. GOOS is a model for how a monitoring program or observation system can serve a variety of users and goals. Lastly, a comprehensive management approach is needed to address the risks from waterborne pathogens. HACCP provides a step-by-step approach to implement a management plan based on risk assessment. The adoption of an Environmental Pathogens Strategy for the Great Lakes basin could provide an effective mechanism to address long-standing microbial contamination issues that currently impact human health.

The Science Advisory Board recommends to the IJC that:

- **The Parties create an Environmental Pathogens Strategy, similar to the Binational Toxics Strategy, to establish an inventory of baseline data for the United States and Canada and to undertake a complete analysis of pollution reduction scenarios for key sources and determine their effectiveness in reducing microbial contamination of the waters of the Great Lakes basin.**
- **The Parties invest substantially in research and pilot studies for the removal of pathogens from wastewater treatment plant effluents, environmentally friendly sludge disposal, and strategically upgraded wastewater treatment infrastructure.**
- **The Parties create a waterborne disease registry for the Great Lakes basin.**

5.8 References

Waterborne Microbial Pathogens in the Great Lakes

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REPORT OF THE GREAT LAKES SCIENCE ADVISORY BOARD

Chemical Exposure and Effects in the Great Lakes Today

5.9 Introduction

As part of the Science Advisory Board's (SAB) activities to maintain current knowledge of health effects in the Great Lakes basin, the Work Group on Ecosystem Health invited a series of expert presentations and consultations during the 2003-2005 biennial cycle. The culmination of these activities was a conference held March 29-31, 2005 in Chicago entitled, Chemical Exposure and Effects in the Great Lakes Today. Twenty-two investigators considered the outcomes of the most current epidemiological and wildlife studies on chemical exposure and effects. A list of conference participants is in Chapter 6.4. The following summarizes the current state of knowledge on these topics.

Table 1. Concentrations of Persistent Toxic Substances in Great Lakes Sport Fish, 1999-2000.

Concentrations are expressed as ng/g (ppb) wet weight. Data supplied by Swackhamer.

LAKE	SPECIES	YEAR	Total PCBs	Total DDTs	Mercury	Dieldrin	Toxaphene	Total Chlordanes
Superior	Lake trout	1999	272	167	123	21	673	62
	Lake trout	2000	784	567	433	31	2493	321
Huron	Lake trout	1999	918	504	144	36	467	120
	Lake trout	2000	779	557	144	32	676	122
	Chinook salmon	2000	719	362	NA	16	395	94
Michigan	Lake trout	1999	1865	883	127	96	813	292
	Lake trout	2000	1614	1056	146	90	1123	303
	Coho salmon	2000	563	257	124	9	192	54
Erie	Walleye	1999	569	95	124	9	31	29
	Walleye	2000	1241	85	114	12	232	27
	Coho salmon	2000	473	52	127	6	107	23
Ontario	Lake trout	1999	1294	594	123	64	169	122
	Lake trout	2000	1174	864	115	45	521	120

Data for lake trout and walleye are means for ten composites, each containing five whole fish. Data for salmon are means for three composites, each containing skin-on fillets from five fish. The Lake Michigan data are the grand means for four sites. NA – not available.

5.10 Exposure

Despite decades of action to reduce toxic chemical discharges and clean up contaminated sediments, recent monitoring confirms that persistent "legacy" chemicals such as polychlorinated biphenyls (PCBs), dioxin, and methylmercury (MeHg) still pose hazards to fish and wildlife and, therefore, people in the Great Lakes region (Table 1). The concentrations of PCBs and total DDT and its metabolites in fish and wildlife tissues showed almost no decline between 1990 and 2000.

Much of the available monitoring data relate to contaminant concentrations in fish tissue. The U.S. Environmental Protection Agency's (EPA) Great Lakes Fish Monitoring Program consists of an open lake trends monitoring component and a game fish fillet component. Ontario's Sport Fish Contaminant Monitoring Program monitors the concentrations of selected contaminants in sport fish and posts regularly updated fish consumption advisories.

U.S. EPA's open lake trends monitoring component monitors contaminants in the open waters of all of the Great Lakes using predatory fish (lake trout in lakes Superior, Michigan, Huron, and Ontario and walleye in Lake Erie). Ten composites of five whole fish within the size range of 600-700 millimetres are analyzed. The PCB concentrations measured in 2000 represent decreases of 53 percent (Erie) to 93 percent (Michigan) from the highest recorded value. While PCBs and DDT declined rapidly in all the lakes immediately following regulatory actions in the early to mid-1970s, the rates of decline slowed for both compounds in lakes Superior, Huron, and Michigan beginning in the mid-1980s. In fact, there has been no statistically significant decrease in either chemical in Lake Superior, or for DDT in lakes Huron or Michigan since the mid-1980s. The current half-life for PCBs in lakes Huron and Michigan is 10-15 years, compared to four to six years in the 1970s.

PCB concentrations in fillets of some large lake trout from Lake Michigan exceed by 40 fold the level (0.05 ppm) which would allow unrestricted consumption. These large lake trout still exceed the 2 ppm tissue criterion for "do not eat" advice for all populations following the Great Lakes Protocol for a Uniform Sport Fish Consumption Advisory. PCB concentrations in popular Lake Michigan sport fish remain at levels that require fish consumption advice ranging from "1 meal per week" to "do not eat" depending on the fish species and size (Schrank, personal communication). One of the progress goals of U.S. EPA's Great Lakes Strategy 2000 is a "25% decline in PCBs in whole lake trout and walleye samples between 2000-2007." A detailed analysis of the available data suggests that the probability of meeting this goal is negligible and, instead, predicts a decline of seven to nine percent (Stow *et al.* 2004). The rate of decline in lakes Erie and Ontario has not changed with time, and the half-lives of PCBs and DDT are nine to eighteen years (Swackhamer, personal communication).

U.S. EPA's game fish fillet monitoring component of the Great Lakes Fish Monitoring Program monitors potential human exposure to contaminants through consumption of popular sport fish (coho and chinook salmon, and steelhead trout in Lake Erie). Contaminants are measured in three composites, each containing skin-on fillets from five fish. The PCB concentrations in the fillets of all sport fish collected in 1999 and 2000 and all whole lake trout exceed the Great Lakes Water Quality Agreement objective for protection of fish-eating wildlife. Of the 19 fillet composites, PCB concentrations in only one were low enough to allow consumption of one meal per week, while concentrations in 14 composites would restrict consumption to one meal per month. Those in the remaining four would restrict consumption to six meals per year. The concentration of DDT in one lake trout composite exceeded the Agreement objective for protection of fish-eating wildlife. Toxaphene concentrations in eight samples exceed the lowest Ontario advisory action level of 235 ppb.

Although salmonids may be sought by sport fishers, subsistence fishers usually catch yellow perch, walleye, rock bass, white bass, smallmouth bass, and other species that can be harvested with low-tech gear from shore. Contaminant concentrations in these species are monitored by Ontario's Sport Fish Contaminant Monitoring Program, but not by U.S. EPA's game fish fillet monitoring component, and may differ greatly from those in sport-caught fish. According to the *Guide to Eating Ontario Sport Fish* (Ontario MOE 2005), several of these species should not be consumed by women of child-bearing age and children under 15 if caught in Areas of Concern (AOCs) in Lake Ontario. The mean concentration of PCBs in 22 white bass and 50 walleye caught by subsistence fishers in the Fox River were 2,200 and 1,400 ng/g (ppb), respectively (Schantz, presentation). On the basis of the *Guide to Eating Ontario Sport Fish*, white bass from the Fox River should not be eaten, and only six meals of walleye should be eaten per year. This highlights the dilemma of the subsistence fisher.

These findings are of concern given the State of the Lakes Ecosystem Conference's (SOLEC) desired outcome of fishability, which states, "There shall be no restrictions on the human consumption of fish in the waters of the Great Lakes basin ecosystem as a result of anthropogenic inputs of persistent toxic substances."

Available evidence suggests that the concentrations of polybrominated diphenyl ethers (PBDEs) and perfluorooctane sulfonate (PFOS), two emerging contaminants (Table 2), are doubling every three and ten years, respectively. ***If present rates of change continue, total PBDE concentrations could surpass PCB concentrations in lake trout tissues within a decade. Insufficient data are available to establish consumption guidelines for these toxic substances.***

Great Lakes sport and subsistence fishers consume considerably more fish than the general population and therefore have higher body burdens of persistent toxic substances (DeRosa, presentation). In the New York State Anglers cohort (Bloom, presentation) and in groups of fishers who consumed fish from lakes Erie, Huron, and Michigan (Anderson *et al.* 1998), serum polychlorinated dibenzo-para-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), and co-planar PCBs were markedly greater than for the general population. PCB and DDE levels were significantly associated with age and fish consumption histories (Hanrahan *et al.* 1999), and years of sport-caught fish consumption was the most robust predictor of serum PCBs. Mercury levels were significantly associated with levels of fish consumption in Lake Ontario sport and subsistence fishers (Cole *et al.* 2004). In a study of pregnant women residing along the upper St. Lawrence River, serum PCBs increased with age (Mergler, presentation).

While the concentrations of most persistent and bioaccumulative "legacy" contaminants have decreased substantially in the last 30 years due to source regulation, mercury concentrations have not decreased or have increased due to emissions from coal-fired power plants and other sources. Elemental and inorganic mercury, deposited in water bodies, can be methylated to form MeHg by microorganisms in sediment. MeHg bioaccumulates through the food chain and can cause decrements in neurobehavioral function in children. MeHg is the leading cause of sport fish consumption advisories in the U.S. and Canada (Wood and Trip, 2001, U.S. EPA, 2001a, U.S. EPA Office of Water, 2002).

Table 2. Concentrations of Polybrominated Diphenyl Ethers, Perfluorooctane Sulfonate, Nonylphenol, and Nonylphenol Ethoxylate in the Great Lakes

CHEMICAL	YEAR	SPECIES OR MEDIUM	LAKE OR LOCATION	CONCENTRATION in parts per billion unless indicated	CITATIONS
Total PBDEs	1997	Lake trout	L. Michigan	126 (5)[a]	Stapleton & Baker 2003
	1997	Smelt	L. Michigan	11 (5)	
	1997	Alewife	L. Michigan	36 (5)	
	1997	Sculpin	L. Michigan	3 (5)	
	1997	*Diaporea*	L. Michigan	2 (5)	
	1997	*Mysis*	L. Michigan	1 (5)	
	2000	Lake trout	L. Superior	180 (6)	Swackhamer (personal communication)
	2000	Lake trout	L. Huron	94 (6)	
	2000	Lake trout	L. Michigan	355 (6)	
	2000	Walleye	L. Erie	51 (6)	
	2000	Lake trout	L. Ontario	227 (6)	
	2003	Snapping turtle eggs	Hamilton Harbour	107 (9)	Fernie & Letcher (personal communication)
	2000	Herring gull eggs	13 colonies around GLs basin	200-1400 (7)	Norstrom *et al.* 2002
	97-99	Beluga blubber	St. Lawrence Estuary	156-935 (10)	Lebeuf *et al.* 2004
Total PFOS	2000	Lake trout	Lakes Superior Michigan, Ontario	13-35	Swackhamer (personal communication)
	2001	Lake trout	L. Ontario	186	Martin *et al.* 2004
	2001	Smelt	L. Ontario	182	
	2001	Alewife	L. Ontario	50	
	2001	Sculpin	L. Ontario	600	
	2001	*Diporea*	L. Ontario	460	
	2001	*Mysis*	L. Ontario	143	
	91-93	Bald eagle nestling plasma	GLs shorelines	330 <1-2220	Kannan *et al.* 2001a
	95-96	Mink liver	Fox River, Wisconsin	5140	Kannan *et al.* 2002
	2003	Water	L. Erie and Ont.	31 and 54 ppt	Boulanger *et al.* 2004
	02-04	Surficial sediments	Lakes Superior Michigan, Huron, Erie	1.0 – 4.0 ng/g	Song *et al.* 2005, Zhu & Hites 2005
NP + NPEO[b]	98-00	Carp	Cuyahoga & Detroit R.	32 -920	Rice *et al.* 2003, Schmitz-Afonso *et al.* 2003
	98-99	Carp and walleye	Near WWTP outlet	4750	Schmitz-Afonso *et al.* 2003
	1999	7 fish species	Kalamazoo R.	< 3- 29	Keith *et al.* 2001
		Herring gull liver	Lower Great Lakes	225-464	Grasman *et al.* in preparation.
	1998	Sediments	Cuyahoga R.	250-1020	Rice *et al.* 2003
	1998	Sediments	Detroit and Rouge R.	<10-60000	Kannan *et al.* 2001b
	1998	Water	Cuyahoga R.	0.13 -5.1	Rice *et al.* 2003

[a] Number in parenthesis is number of PBDE congeners measured [b.] NP - nonylphenol, NPEO – nonylphenol ethoxylate

5.11 Effects

In the 1960s and 1970s, numerous studies documented reproductive failures in lake trout, mink, and fish-eating birds; gross deformities in fish-eating birds; and tumours and other deformities in bottom-dwelling fish. These findings pointed to the presence of significant quantities of unidentified toxicants in the Great Lakes capable of affecting the health and well-being of animals that eat fish, drink, and swim in the Great Lakes. Although there were few investigations of health effects or chemical exposure at that time, these concerns were reflected in the 1978 Agreement.

A 1991 basinwide assessment of the health of herring gulls nesting in 11 colonies representing all five Great Lakes, relative to two reference colonies outside of the basin, revealed widespread DNA damage (Fox *et al*. 2005) and chronic periportal hepatitis (inflammation of the liver) and interstitial nephritis (inflammation of the kidney). These effects were more severe in highly contaminated colonies. There was evidence of decreased biosynthetic activity and intermediary metabolism in the liver and altered glucose and mineral homeostasis. Great Lakes gulls suffered from hypothyroidism and had enlarged hyperplastic thyroid glands. These toxipathic responses were most frequently associated with PCBs. Studies of pre-fledgling herring gulls in 1994-1999 in lakes Huron, Erie, and Ontario revealed marked suppression of T-cell-mediated immune function and altered antibody production (Grasman *et al.* 1996). Studies of herring gulls in colonies in the Detroit River, western Lake Erie and Lake Ontario 2001-2004 revealed that biochemical, thyroid, and immune effects still persist. In addition, there were effects on corticosterone secretion and, at some sites, the plasma of males contained vitellogenin, suggesting they were exposed to biologically significant concentrations of estrogens. Similar biochemical effects were seen in male snapping turtles, and thyroid effects were seen in snapping turtles and fish. Vitellogenin was also found in the plasma of male fish and snapping turtles. The surveys revealed decreased embryo viability in herring gull eggs and decreased hatching success in snapping turtles at some AOCs. Detailed studies revealed altered reproductive steroid levels and production in fish at some sites. The livers of 57 percent of mink collected from 1999-2002 from western Lake Erie tributaries and marshes contained PCB concentrations greater than the lowest-observable-effect level for reproductive impairment (Fox, presentation).

Recent research revealed significant negative associations between mercury concentrations in the cerebrum and the numbers of cholinergic and dopaminergic receptors in the cerebral cortex of river otters and mink trapped in Ontario, Nova Scotia, and Yukon Territory, suggesting that environmentally relevant concentrations of mercury may exert sub-clinical neurotoxic effects on fish-eating mammals (Basu *et al.* 2005a, 2005b). Gonzalez *et al.* (2005) monitored the expression of 13 genes associated with responses to chemical stressors in the brains, muscles, and livers of zebra fish exposed to environmentally relevant concentrations of MeHg for nine weeks. They observed altered expression of multiple genes in the muscles and liver, but no response in the brains, despite the brains having accumulated the highest concentration of MeHg. This may suggest that the brain has no inherent ability to demethylate MeHg and deal with its toxicity. When Hammerschmidt *et al.* (2002) fed juvenile fathead minnows diets containing concentrations of MeHg present in some aquatic food webs through to their sexual maturity, they found no overt toxicity. However, gonadal development of females was reduced leading to delayed spawning and reduced spawning success. The offspring of adult killifish fed environmentally relevant concentrations of MeHg had altered sex ratios and lowered reproductive success in adults with whole body concentrations of 440 to 1200 ng/g (ppb) (Matta *et al.* 2001).

Pesticides are an ongoing concern, just as they were in the 1960s. Although atrazine has been banned by the European Union, it is still in use in the U.S. and Canada. It is, however, under regulatory review in both countries. Although controversy surrounds the studies undertaken to clarify its safety to amphibian development, the weight of evidence suggests that it is toxic to amphibians at or near concentrations currently measured in aquatic environments (Hayes 2004).

5.12 Special Consultation on Mercury

During the priority cycle, the Work Group on Ecosystem Health closely followed published reports regarding human-health effects due to exposure to MeHg, and consulted with mercury experts. Numerous reports have raised concerns regarding MeHg in sport fish and adverse health risks, particularly to the developing child (National Research Council 2000, Great Lakes Science Advisory Board 2003, Gilbertson and Carpenter 2004). For example, the National Research Council (NRC) concluded that "the population at highest risk is the children of women who consumed large amounts of fish and seafood during pregnancy." Its report concluded that the risks to that population are likely 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. Subsequent information continues to indicate public health concerns, including potential cardiovascular effects, as do national fish consumption advisories issued by the U.S. Food and Drug Administration and U.S. EPA (U.S. FDA and EPA 2004). Current research focuses on three main questions:

- What are the most appropriate human-health measures to assess mercury impacts in adults and children?
- What is the nature of mercury-related human-health impacts?

- Is there a threshold blood-mercury level below which impacts on cognition are not seen?

Dr. Allen Stern was a member of a panel of scientists charged by the NRC to evaluate MeHg health effects. In its report, the NRC supported U.S. EPA's methodology to derive a reference dose (RfD) for acceptable chronic exposures to MeHg. The RfD of 0.1 microgram (ug) MeHg per kilogram of body weight (kg-bw) per day, a maternal dose, was based on developmental effects of mercury assessed in children who have been exposed to mercury *in utero* through the maternal diet (U.S. EPA 2001b, Rice 2004, Stern 2005a). The RfD was derived from MeHg in fetal-cord blood to a reconstruction of the maternal dose that gives rise to blood levels in the fetus. Using data from three epidemiological studies conducted in New Zealand, the Faroe Islands, and Seychelles Islands, the NRC determined that a fetal-cord blood of 58 micrograms per liter (ug/L) was associated with twice the probability of adverse neurological effects in children (National Research Council 2000, Rice 2004, Stern 2005a).

Following recommendations from the NRC committee and U.S. EPA peer reviewers, U.S. EPA applied an uncertainty factor of ten to derive a concentration of 5.8 ug/L in fetal-cord blood from which to calculate an RfD without a significant increased risk of adverse neurological effects in children (Rice 2004, Stern 2005a). The factor of ten included a factor of three for variation in maternal elimination of MeHg (pharacokinetic variability) and a factor of three for pharmacodynamic variability (Rice 2004, Stern 2005a, U.S. EPA 2001b).

Stern's published work supports the appropriateness of directly estimating the percentile of maternal dose corresponding with fetal-cord blood levels (Stern 2005a). While U.S. EPA based the RfD on the assumption of a 1:1 ratio of mercury in fetal cord to maternal blood, more recent evidence found the ratio to be 1.7:1.0. This lowers the maternal dose at which adverse effects may occur in the fetus (Mahaffey *et al.* 2004, Rice 2004, Stern 2005a, Morrissette *et al*. 2004). Stern's analyses indicated that U.S. EPA's determination of the RfD would agree within a factor of two based upon his work. Using his findings, a benchmark RfD based on the first percentile maternal dose corresponding to a cord-blood concentration of 58 ug/L and incorporating an uncertainty factor of three would be 0.07 ug MeHg/kg-bw/day.

These findings suggest that future fish-consumption advisories in the Great Lakes region, which are largely issued to protect women of child-bearing age and children, may need to be extended to other segments of the population (such as adult males, etc.).

There is no evidence to date that a threshold blood-mercury concentration exists where effects on cognition are not seen. The NRC (2000) concluded that the likelihood of neurobehavioral deficits increased as cord-blood concentrations increased from 5 to 58 ug/L (the U.S. EPA benchmark dose). Trasande *et al.* (2005) used 5.8 ug/L in cord blood, the lowest concentration at which adverse neurodevelopmental effects were demonstrated in cohort studies (Grandjean *et al.* 1997, Kjellstrom *et al.* 1986, 1989) and applied the cord blood: maternal blood ratios of 1.3:1.0 (Budtz-Jorgensen *et al.* 2002) and 1.7:1.0 (Stern 2005a) to derive a range of maternal blood mercury concentrations above which neurobehavioral deficits would be expected. These values are 3.4 to 4.5 ug/L. Based on blood-mercury concentrations obtained for the 1999-2000 National Health and Nutrition Examination Survey, Mahaffey *et al.* (2004) calculated 9.7 and 15.7 percent of American women 16 to 49 years would have blood-mercury concentrations of $\geq$5.0 ug/L and $\geq$3.5 ug/L, respectively. The geometric mean blood-mercury concentration for a sample of Asian-Canadian subsistence fishers who fished in five Great Lakes AOCs was 7.9 ug/L (Cole *et al.* 2004). Anderson *et al.* (1998) found geometric mean blood total mercury concentrations in samples of high sport-fish consumers from lakes Michigan, Huron, and Erie ranged from 3.2 ug/L (Erie) to 4.7 ug/L (Michigan).

Stern reviewed information available since publication of the NRC report regarding MeHg exposure via fish consumption suggesting an association with heart attacks, ischemic heart disease, hypertension, and heart-rate variability. He provided an overview to the SAB based on a recently published literature review (Stern 2005b). In his view, the current evidence suggests an association between rates of MeHg exposure from fish consumption with heart disease, particularly myocardial infarction. The causal mechanism may be an antagonistic interaction between MeHg and fatty acids, which provide health protection from heart disease. A study of 1,871 men in a Finnish cohort (Virtanen *et al*. 2005) provides the strongest basis for a formal quantitative risk assessment of the cardiovascular effects of MeHg, although a quantitative relationship between exposure and effects has yet to be developed.

Dr. Ellen Silbergeld of Johns Hopkins Medical School also presented her research that suggests that mercury is an immunotoxin that, in the appropriate rodent model, triggers autoimmunity and autoimmune myocarditis. The immunotoxic effects of mercury in rodents occur at significantly lower doses than other effects.

These findings suggest that future fish-consumption advisories in the Great Lakes region, which are largely issued to protect women of child-bearing age and children, may need to be extended to other segments of the population (such as adult males, etc.).

5.13 Health Effects of Toxic Contaminants

In the late 1980s, Health Canada and the U.S. Agency for Toxic Substances and Disease Registry (ATSDR) initiated Great Lakes health effects programs that provided funding for investigations of human exposure to toxic contaminants and establishment of human cohorts for cross-sectional and prospective epidemiological studies. Numerous epidemiological studies have documented effects on human reproduction and development, metabolism, endocrine and immune function associated with Lake Ontario, Lake Michigan, and the St. Lawrence River (Johnson *et al*. 1998). Adverse health effects are evident even in those individuals that consume relatively small amounts of certain Great Lakes fish. Relatively few health-effects data exist for subsistence fishers who consume larger amounts of more contaminated fish. Several well-designed studies are in progress.

The following summarizes current research on the health effects of toxic contaminants in the Great Lakes basin.

5.13.1 Reproductive Success

Scientists from the University of Buffalo investigated various reproductive outcomes in members of the New York State Angler Cohort. They found associations between maternal sport-fish consumption and a delay in the probability of conception (Buck *et al.* 2000). There was also an association between sport-fish consumption by males and reduced probability of fathering a male child (Travers *et al.* 2000). However, studies of Lake Michigan anglers showed a higher proportion of males in offspring of fathers with serum PCB concentrations greater than 8.1 ug/L (Karmaus *et al.* 2002).

Investigators from the University of Quebec at Montreal found an association between cord blood-serum PCBs and birth weight in a cohort of 159 pregnant women living along the upper St. Lawrence River (Lafond and Mergler, 2005). This is consistent with earlier studies of effects of maternal consumption of Lake Michigan fish (Fein *et al.* 1984). In a more recent study of Lake Michigan sport fishers, there was an association between maternal serum DDE, but not PCBs. Concentrations and birth weight effects associated with Great Lakes sport-fish consumption have decreased over time (Weisskopf *et al.* 2005). Investigators from the Institute for Health and the Environment at the University of Albany found a significant association between lower birth weight and parental residence near a PCB-contaminated site in more than 900,000 births in New York State (Baibergenova *et al.* 2003).

In a study of 159 women who resided near the upper St. Lawrence River, a negative association existed between their blood-lead concentration and the rate of calcium uptake by their placental syncytiotrophoblasts - the layer of placental cells that regulates the flow of nutrients between mother and fetus (Lafond *et al.* 2004).

Scientists from the Institute for Health and the Environment have conducted studies of Mohawk youth at the Akwesasne Reserve which is just south of Cornwall, Ontario. Their analysis of multi-chemical exposure among adolescent Mohawk girls suggested that the age of attainment of menarche may be sensitive to relatively low levels of lead and certain PCB congeners (Denham *et al.* 2005).

Among the 2,237 infants born to female members of the New York State Angler Cohort between 1986 and 1991, there was an increased probability of a major malformation (including hypospadias, cleft palate, and musculoskeletal defects) in males but not females, whose mothers consumed two or more sport fish meals per month during pregnancy (Mendola *et al.* 2005).

5.13.2 Neurobehavioral Effects

Researchers are discovering an increasing suite of behavioral abnormalities in infants and children and in laboratory rodents prenatally exposed to environmentally relevant concentrations of PCBs or mercury. Numerous papers have documented persistent effects on neurobehavioral development associated with maternal consumption of Lake Michigan fish (the Jacobsons and colleagues 1986, 1990, 1992, 1996). These findings have been substantially duplicated by investigators from the Center for Neurobehavioral Effects of Environmental Toxics, SUNY Oswego for a cohort of children whose mothers consumed Lake Ontario fish. In this longitudinal study, prenatal PCB exposure was consistently predictive of cognitive and behavioral deficits in children from birth to age five (Stewart *et al.* 2000b, Stewart *et al.* 2003b).

The most robust associations were between measures of attention and impulse control and highly chlorinated PCB congeners. These findings also have been confirmed with laboratory animals (Stewart *et al.* 2000a). In a subset of these children, the risk of abnormal performance increased markedly in those individuals with a smaller splenium, suggesting that contaminants may have a much larger impact in some children than in others (Stewart *et al.* 2003a). Scientists from the University of Buffalo investigated gender-associated behaviors in more than 1,000 children born to members of the New York State Angler Cohort. They found an exposure-associated increase in masculine behavior in young males (Sandberg *et al.* 2003).

Investigators at the University of Illinois at Urbana-Champaign assessed the impact of PCBs and other fish-borne contaminants on intellectual function in older members of the Lake Michigan sport-fisher cohort. They found that PCB exposure during adulthood was associated with impairments in memory and learning, but not executive or visual-spatial function (Schantz *et al.* 2001). These investigators are now studying the combined exposure to PCBs and MeHg, two of the most widespread chemical contaminants that are responsible for almost all Great Lakes fish-consumption advisories. Since both are developmental neurotoxicants, there is potential for interactive effects on the nervous system. The investigators are characterizing the cognitive, motor, and sensory effects of developmental exposure to these toxicants in animals, and will use their findings to guide selection of outcome measures for infants and children. Both PCBs and MeHg caused deficits in working memory, but there was no additivity (Widholm *et al.* 2004). Neither chemical caused significant effects on balance or coordination when administered alone, but combined exposure caused a deficit (Roegge *et al.* 2003). PCBs, but not MeHg, caused deficits in auditory function, and there was no additivity (Lasky *et al.* 2002).

5.13.3 Other Effects

In pregnant women who resided on the shores of the upper St. Lawrence River, there was an inverse association between plasma concentrations of total triiodothyronine and three non-coplanar, highly persistent PCB congeners, DDE, and hexachlorobenzene (HCB) (Takser *et al.* 2005). In Mohawk youth from Akwesasne, also located on the St. Lawrence River, concentrations of thyroid-stimulating hormone were increased, and decreases were found in thyroxine and free thyroxine associated with some PCB congeners and lead (Schell, presentation). In studies of 66 males from the New York State Angler Cohort, there was a negative relationship between thyroxine and HCB (Bloom, presentation). In a grouping of high sport-fish/wildlife consumers and non-consumers, free thyroxine with the lipid-adjusted concentrations of total dioxins was significantly decreased (Bloom *et al.* in press). Among a subset of 178 men and 51 women studied by the Great Lakes Consortium, a relationship was found between fish consumption and serum PCB concentration and serum thyroxine (Persky *et al.* 2001). There was also an association between both PCBs and fish consumption, and sex hormone-binding globulin-bound testosterone in the males (Persky *et al.* 2001).

A recently published study of adult Mohawks from Akwesasne has shown associations between plasma PCB concentrations and induction of cytochrome P450 1A2, an enzyme involved in sex steroid hormone synthesis. The study also showed metabolic activation by a number of toxicants and carcinogens (Fitzgerald *et al.* 2005).

McElroy *et al.* (2004) found an increased relative risk of developing breast cancer of 70 percent in pre-menopausal Wisconsin women who recently consumed Great Lakes sport-caught fish.

Michigan investigators found a significantly increased relative risk for inner ear infections for the combined effect of DDE + PCBs or DDE + HCBs (Karmaus *et al.* 2001). They also found significantly higher relative risk for asthma and increased immunoglobulin E concentrations with DDE exposure, suggesting impacts on immune function.

The half-life of a particular contaminant is of considerable importance in determining its relevance to society. The half-life of MeHg in the human body is about 70 days, whereas the half-life for organohalogen compounds can be as long as ten years. This difference has great significance for reducing the danger of neurobehavioral decrements to the fetus. If a young woman stops eating MeHg-contaminated fish a year prior to getting pregnant, she can clear her body of most of the MeHg. However, if she waits until she's ready to get pregnant to stop eating organohalogen-contaminated fish, it will be too late to reduce her levels of these contaminants. Her body burdens will reflect her previous exposure.

5.13.4 Health Effects of Living in Areas of Concern

In 1998, Health Canada reported on retrospective epidemiological evidence for each of the 17 Canadian AOCs (Elliot *et al.* 2001). They used mortality, hospital admissions/separations, and cancer data for 1986-1992 to calculate morbidity, mortality, and incidence rates. The data suggested that there was increased morbidity and mortality for a variety of health effects associated with residence in these AOCs relative to the Province of Ontario as a whole. Also, residence in a particular location was found to adversely affect health independent of whether Great Lakes fish is consumed.

The Health Canada studies for the various Canadian AOCs found increased incidence of genital-tract disorders, thyroid disease, diabetes, ischemic heart disease, chronic obstructive pulmonary disease, and asthma. These findings led investigators at the Institute for Health and the Environment at the University of Albany to test a series of hypotheses based on the assumption that these health end points are associated with place of residence. Using a variety of available health data collected in the 1990s, they tested these hypotheses for individuals living near the nearly 900 contaminated sites identified in New York state, including AOCs. They found convincing evidence that a number of chronic and acute diseases occur more commonly in patients who reside near hazardous waste sites and AOCs containing priority pollutants, especially persistent organic pollutants such as PCBs (Carpenter presentation). The elevated incidence is not accounted for by socio-economic status or lifestyle factors such as smoking, diet, or exercise. These findings imply that inhalation is a major route of exposure (Sergeev and Carpenter 2005, Baibergenova *et al.* 2003). Effects documented include adverse impacts on reproduction and development, metabolism, and endocrine and immune functions. In addition, studies suggest that increased risks of heart disease, chronic obstructive pulmonary disease, and diabetes are associated with residence near AOCs and hazardous waste sites (Carpenter presentation). A recently published study has also shown a strong association between ambient air pollution and respiratory hospitalization in the Windsor AOC (Luginaag *et al.* 2005).

Inhalation can be a major route of exposure. The health of large numbers of people in many communities in the Great Lakes basin may be compromised by multi-media exposure to the contaminants in their environment. A much greater focus on place of residence and multi-media exposure is needed, in addition to fish consumption, if the health impacts of contaminated sites and other contaminant sources on communities and populations in the basin are to be understood.

Preliminary analyses of data and statistics for the hospitalization rates of males for cerebral palsy in the 17 Canadian AOCs indicate a possible geographic association with locations with elevated mercury from natural or industrial sources (Gilbertson 2003). It should be noted that the amount of mercury released from cloralkali plants in Sarnia and Cornwall (Trip and Thorleifson 1998) exceeds the estimated amounts released into Minimata Bay by a factor of four and two times, respectively (Gilbertson 2003).

The costs of learning and behavioral problems, low birth weight, immune system disorders, and other effects are real and are borne by individuals, families, and communities. Grosse *et al.* (2002) have estimated that the economic benefit resulting from improved cognitive ability (IQ points) associated with reductions in children's exposure to lead in the United States ranges from $110 billion to $319 billion annually. Using similar methodologies, Trasande *et al.* (2005) have estimated the U.S. cost of loss of intelligence in children born each year with deficit-associated cord-blood mercury levels, an effect that persists throughout the life of each individual. An estimated $7.8 billion (ranging from $2.2 to $44 billion) is lost annually through the associated loss in productivity. Of this, $1.3 billion is attributable to mercury emissions from American power plants.

These findings emphasize the individual and community impacts of toxic chemical pollution. Future research on the health effects of contaminants in the Great Lakes basin will therefore be most effective if it is community-based and participatory. In collaboration with the Children's Environmental Health Centers, Schantz and others are using such an approach to conduct a prospective cohort study of children born to Hmong immigrants who eat contaminated fish from the Fox River.

5.14 Managing Chemicals to Protect Human Health and the Environment

In the Great Lakes basin, three approaches have been used to manage chemicals in the environment: fish consumption advisories; mitigation of existing sources; and prevention/control at source. Underpinning all three efforts is a requirement for adequate monitoring systems to track not only concentrations (exposures), but also human health and ecosystem effects. New or newly detected chemicals in the environment must also be identified. The following summarizes current research in these areas.

5.14.1 Fish Consumption Advisories

Fish consumption is one of the main routes by which toxic substances enter the human body. Fish-consumption advisories were created almost 30 years ago to protect those who consume sport fish. While advisories provide excellent advice, they have limited effectiveness, in part because they focus on sport fishing. Subsistence fishers who depend on Great Lakes fish to feed their families often eat species that are not covered by advisories. In addition, the current emphasis on sport fishing tends to target male sport fishers rather than subsistence fishers, many of whom are women and minorities. These latter groups are largely unaware of the dangers of contaminated fish. One-size-fits-all advisories therefore are less effective than originally intended. The most vulnerable populations of fishers need to be identified and specifically targeted with clear advisories that address ethno-cultural, nutritional, and economic concerns.

The goals of Great Lakes sport-fish consumption advisories are to maintain the health benefit of fish consumption while minimizing toxic chemical exposure, and thus present information in a way that maximizes voluntary compliance. However, in trying to simplify language for the consumer, many advisories introduce unintended confusion and provide little detail as to their basis. In some systems, a single pollutant such as mercury may be responsible for most of the fish-consumption advisories; in others, multiple pollutants may be of concern.

The Ontario Sport Fish Contaminant Monitoring Program covers the most common species of sport fish for 1,700 locations across the province. Boneless, skinless fillets of dorsal muscle are tested. A variety of species and locations are selected based on:

- Their popularity;
- Suspected sources of pollution;
- Importance as a source of food for the local community;
- Recreational development; or
- Long-term monitoring sites.

The *Guide to Eating Ontario Sport Fish (2005-2006 edition)* (Ontario MOE 2005) provides location-specific contaminant data and excellent information aimed at anglers (and their families) who consume moderate amounts of fish. The *Guide* provides separate advice for "the sensitive population of women of child-bearing age and children less than 15 years of age" and explains the basis for this precaution. It also suggests that these individuals should further reduce their consumption if they regularly eat processed fish. The *Guide* is written in English and French, and two-page summary brochures are available in 16 other languages covering the majority of subsistence fishers. The notice of their availability, however, is only in English. The notice would be more accessible if written on the back cover in all 16 languages. The brochure's focus is proper use of the *Guide,* but does emphasize the separate advice for women of child-bearing age and children. Another educational brochure for women of child-bearing age is available in English only, on request. One brochure, containing the essence of both and available in all 16 languages, would be an improvement.

According to the *Guide,* the overall percentage of fish consumption advice that results in some level of restriction for the general population ranges from 37 percent (Lake Superior) to 57 percent (Lake Ontario). PCBs are responsible for 25 percent (Lake Superior) to 79 percent (Lake Ontario) of the advisories. Mercury is responsible for two percent (Lake Erie) to 32 percent (Lake St. Clair, the St. Clair and Detroit Rivers) of the advisories. Dioxins are responsible for 17 percent (Lake St. Clair, the St. Clair and Detroit Rivers) to 65 percent (Lake Superior) of the advisories. No single advisory describes both lipid-soluble contaminants such as PCBs or dioxins as well as MeHg, which is confusing to fish consumers.

An important question is the effectiveness of current advisories. The Consortium for the Health Assessment of Great Lakes Sport Fish Consumption conducted approximately 1,000 telephone interviews in each of seven Great Lakes states in 1994, prior to the introduction of the Uniform Great Lakes Sport Fish Consumption Advisory and about 500 interviews in each state in 2001. The results suggest that the numbers of individuals consuming fish and the amount of Great Lakes sport fish consumed had not decreased. Awareness of the advisories had increased by five to ten percent in higher-consumption categories and in males, but had decreased in females and non-white fishers. Compliance had increased most for cooking/cleaning and fishing locations, but had not changed for consumption frequency (Anderson, presentation).

In a 12-state initiative to evaluate awareness of sport-fishing advisories for mercury among women of child-bearing age, more than 66 percent of the women who consumed sport fish were not aware that such guidelines even existed (Knobeloch 2005). In a population-based telephone survey of adults residing in the eight Great Lakes states, seven percent of respondents, of an estimated 4.2 million adults, reported consuming fish caught from the Great Lakes. Consumption of Great Lakes-caught sport fish was greatest among residents of Michigan and Ohio (Imm *et al.* 2005). Awareness of advisories varied by gender and race, and was lowest among women (30 percent) and African-American residents (15 percent). However, 70 percent of those who consumed Great Lakes-caught sport fish twice a month or more were aware of the advisories.

In a recent study of pregnant women in southwest Quebec, consumption of St. Lawrence fish decreased and that of commercial fish increased during pregnancy, compared with consumption prior to pregnancy (Mergler, presentation).

Arquette and colleagues (2002) from the Akwesasne Task Force on the Environment note that *"In the case of Akwesasne, it has been found that the traditional cultural practices that express and reaffirm identity and culture increase exposure of community members to toxic substances. Adverse health effects have resulted when Mohawk people are forced to abandon traditional cultural practices in order to protect their health and the health of future generations."*

Ethno-cultural groups who consume Great Lakes fish identified to date include immigrants from a variety of European countries; Asians from Laos, Vietnam, and Bangladesh; African-Americans; and various aboriginal tribes. Investigators collected fish-consumption, health, and contaminant data from fishers on the shorelines of five AOCs: Toronto, Hamilton Harbour, Niagara River, Detroit River, and St. Clair River (Sheeshka, presentation). They surveyed 4,595 participants over five years, 38 percent of whom ate some or all of their catch. From this group, 27 percent ate more than 26 meals per year. Two ethno-cultural groups predominated, Asian Canadians and European Canadians. A sample of 91 high-fish consumers ate 26 to 501 Great Lakes fish meals/year, with a median of 88. Males consumed more often than females and Asians more often than Europeans (Sheeshka, presentation). Although some of these individuals were aware of consumption advisories, the language, culture, economic circumstances, and personal and community experience affected advisory effectiveness. For these fish consumers, perceived benefits outweighed perceived harm.

Fish consumption advisories can only be regarded as a limited and temporary solution for public health protection. The advisories externalize the economic costs to individuals and society by permitting the exposure of fish consumers to toxic chemicals. Advisories must be accompanied by systematic and effective programs to reduce or eliminate discharges of toxic chemicals to the Great Lakes basin.

Rather than "one-size-fits-all," to be effective advice needs to be targeted for specific ethnic communities written clearly in their language, and perceived as personally relevant, practical, and culturally sensitive. Voluntary restriction of one's consumption of contaminated fish requires sufficient knowledge and economic flexibility to make informed choices. The majority of subsistence fishers currently have neither. The goal of fish advisories is to encourage each consumer to eat a varied and nutritious diet, including fish as desired, and to select fish that are lower in contaminants. Providing fishers with comparative risk information that focuses on different foods or protein sources would enable consumers to make appropriate decisions based on fish size, species, location, or food type (Knuth *et al.* 2003). Fish consumers could better make appropriate choices if provided with comparative risk information such as size, species, fishing location, or food type that have, on balance, greater benefits than risks.

Great Lakes sediments contaminated with "legacy" pollutants remain an ongoing source of contaminants. Elimination or reduction of health effects in wildlife and humans in the Great Lakes basin requires removal or capping of contaminated sediment, a technically challenging and expensive process (Clark, presentation). For example, the effort to remove 90 percent of the PCBs from the Fox River, Wisconsin will take at least five years and cost at least $500 million. Some consider this an imperfect solution since residual PCBs will remain in the system for years (Foran, presentation). The relative costs and benefits of such cleanup are hotly debated, in part because most assessments ignore the costs of the environmentally contaminated fish to the health of wildlife and human populations at risk, and the costs associated with lost economic activity.

5.14.2 Detecting and Managing Emerging Chemicals

Within five years of the initial flagging of environmental concerns about PBDEs and PFOs, chemists mapped their global distribution, measured their concentrations in the tissues of humans and numerous other species, determined changes in their compositional pattern, and established temporal trends over periods of 10 to 30 years. This was possible because of tissue archives and the small, dedicated cadre of scientists who systematically collect and properly preserve tissues for just such purposes. Coupled with appropriate analytical chemistry, such archives allow problems to be identified and quantified and thus provide early warning. This "exposure" monitoring is essential to assessments of whether we are moving closer or further away from achieving virtual elimination of toxic chemicals and protecting public health.

While current long-term monitoring programs are adequate to document trends in the *concentration* of contaminants in the Great Lakes environment, there is no formal program in either country to monitor trends in the incidence of *effects* due to the presence of these contaminants. Well-planned monitoring assists scientists in anticipating surprises. Without monitoring of both ambient conditions and the impact on Great Lakes organisms, decision makers are poorly equipped to identify appropriate policy responses or even areas of uncertainty. Such knowledge is also fundamental to developing cost-effective and appropriate research questions.

Effective monitoring programs are complicated by the need for continuously updated analytical methods. Monitoring the vast array and low concentrations of chemicals in the environment is a daunting challenge. In the 1970s and 1980s, gas chromatography/mass spectrometry (GC-MS) was the instrumentation of choice. In the 1990s, the availability of the combination of high-volume sampling, solid-phase extraction, and liquid chromatography/mass spectrometry (LC-MS) allowed the development of more sensitive methods capable of measuring a wide array of chemicals in a single environmental sample.

With increasingly efficient instrumentation and improved sample-preparation protocols, chemists are discovering more persistent or biologically active compounds in water and tissue samples from the Great Lakes environment. The results show increasing numbers and concentrations of chemicals that have been in use for decades that were not previously detected, and for which there are only minimal and/or disturbing health data. Chemicals from pharmaceuticals, personal-care products, and household-cleaning compounds are now found regularly in rivers and lakes receiving municipal effluents. These "emerging" chemicals are found in addition to the widely dispersed persistent, bioaccumulative "legacy" chemicals. Municipal wastewater treatment plant effluents are a major source of many of these "emerging" contaminants to surface waters and biota.

Comprehensive congener-specific, multi-analyte analysis of plasma or serum using a combination of GC-MS and LC-MS is also providing considerable insight into the metabolism and storage of contaminants. Blood plasma bathes all tissues. Frequently, much tighter associations are found between specific metabolites and effects measures, rather than with the parent compounds. Careful examination of congener profiles, using pattern recognition techniques and polytopic vector analysis, can reveal information on sources and subject-dependent factors such as biotransformation enzyme polymorphisms. Such polymorphisms may be very important in determining individual susceptibility (DeCaprio, presentation).

Unfortunately, the instrumentation required for effective monitoring is expensive, the availability of experienced analytical chemists limited, and the financial security of environmental-monitoring programs constantly in question. Therefore, in a May 2004 consultation, the SAB asked for expert advice on how to identify, prioritize, and indeed anticipate "emerging" contaminants of concern.

Derek Muir (presentation) described his search strategy to identify potential chemicals of concern among the approximately 100,000 chemicals in commerce, approximately 70,000 of which are on the Toxic Substances Control Act list created in 1976, and 5,200 that exceed a production volume of 1,000 tonnes/year according to the Organization for Economic Cooperation and Development. Of these 5,200 chemicals, 43 percent had no toxicity data available as of 2004.

A predictive approach that addresses the paucity of available data uses structural, chemical, and physical properties of the chemicals coupled with quantitative structure-activity relationships (QSARs) to identify substances of concern. Due to analytical limitations, only a very low proportion of the large number of potentially troublesome compounds identified as likely present in the Great Lakes environment are currently analyzed in Great Lakes monitoring programs. Of greatest concern are those chemicals used in large quantities and in environmental concentrations similar to, or approaching, those known to cause adverse effects.

Another strategy focuses on chemicals present in environmental media and tissues that are not persistent or bioaccumulative, but are chronically discharged into the aquatic environment. With the exception of pesticides, most of these chemicals are not acutely toxic, but are pharmacologically or hormonally active at very low concentrations. When they contaminate the environment and are consumed unknowingly by humans and species for which they were not intended, they can be toxic. Using new, sophisticated instrumentation and improved sample preparation protocols, chemists today are identifying an increasing suite of these "new" chemicals or groups of chemicals whose concentrations are increasing in water and tissue.

As a result of the May 2004 consultation, the following groups or classes of chemicals are considered "emerging" contaminants of concern in the Great Lakes (see also Table 2):

- Brominated fire retardants (BFRs), PBDEs and tetrabromo bisphenol-A;
- Perfluorinated compounds or PFCs (PFOS, perfluorooctanoic acid, N-ethyl perflourooctane sulfonamidoethanol);
- Phthalates (a large class of plastic additives);
- Pharmaceuticals and chemicals found in personal care and household products (PPCPs);
- Estrogenic and hormonally active compounds (birth control agents, natural estrogens, alkylphenol ethoxylates, bisphenol-A, Trenbolone); and
- Some currently used pesticides (Atrazine).

These chemicals and their uses are described in more detail in Chapter 5.17 (Appendix).

Pharmaceuticals and personal-care products are persistent by virtue of their ongoing release into the environment in human and animal excreta. However, health professionals, agricultural producers, and society are unlikely to forego access to the benefits of these products. Therefore their virtual elimination will require further restrictions on their disposal and release into the environment.

5.14.3 Chemical Mixtures

In addition to awareness of "emerging" chemicals, there is a growing awareness of a larger range of developmental and functional health impacts associated with exposure to mixtures of chemicals, including the persistent "legacy" contaminants and the "emerging" chemicals. It is now clear that a single chemical can have an impact on multiple-organ systems via several exposure pathways and a number of modes of action, and that those impacts can be expressed in multiple ways. Many "emerging" chemicals affect the same target organs and/or systems as the "legacy" chemicals associated with trans-generational impairment.

It is known that the combined effects of a mixture of dioxin-like compounds are additive when adjusted for potency. This has been shown for end points such as various manifestations of reproductive toxicity and for CYP1A induction, which were used to derive the toxic equivalency factors for each chemical. This has now been extended to the assessment of their cancer risk (Walker *et al.* 2004). Recently, investigators discovered that the same holds true for estrogenic chemicals (Brian *et al.* 2005). Crofton *et al*. (2005) dosed young rats with a mixture of two dioxins, four dibenzofurans and twelve PCBs. The mixture was formulated to reflect typical concentrations measured in breast milk, and in fish and other foods. None of the concentrations in any of the doses exceeded the LOELs for the constituent chemicals. The mixture reduced serum thyroxine levels at concentrations that were at least an order of magnitude below their LOELs. The effects on thyroxine were cumulative (additive) at low doses and synergistic at higher doses. The activity of both estrogens and dioxin-like compounds is mediated through specific nuclear receptors. ATSDR has begun to develop interaction profiles, based on *in vivo* and *in vitro* laboratory studies, for some of the most common contaminants of concern in AOCs and contaminated sites, using a weight-of-evidence approach (DeRosa, presentation). *They recommend that mixtures be evaluated using a component-based approach that assumes additive joint toxic action*. A hazard index is calculated as the sum of individual hazard indices (exposure concentration ÷ toxicity threshold) for each component.

Due to analytical limitations, only a very low proportion of the large number of potentially troublesome compounds identified as likely present in the Great Lakes environment are currently analyzed in Great Lakes monitoring programs. Of greatest concern are those chemicals used in large quantities and in environmental concentrations similar to, or approaching, those known to cause adverse effects.

When investigators dosed sexually mature male rats with a complex mixture of organochlorines and metals for 70 days (one full cycle of spermatogenesis), they induced effects on liver physiology and T-cell function at low-to-moderate doses. Effects were also seen on liver, kidney, and general metabolism at high doses, but there was no apparent effect on reproductive physiology (Wade *et al.* 2002a). The mixture consisted of 12 organochlorines and two metals frequently detected in human tissues and were administered at 1, 10, 100, and 1,000 times the tolerable daily intakes (TDIs) for the individual substances. Thyroid-hormone physiology was affected at the lowest concentration that is currently accepted as the TDI (Wade *et al.* 2002b). This is consistent with the findings of Crofton *et al*. (2005). Given that individuals are exposed to chemical mixtures similar to those used by Crofton *et al*. and Wade *et al*., the current TDIs may not be sufficiently protective of thyroid homeostasis or the liver.

5.14.4 Prevention at Source

The "emerging" chemicals highlighted in this chapter illustrate the inadequacy of the current approach to chemical regulation to protect public health and the environment. The question could be asked, "Have we learned anything from the past regarding persistent, bioaccumulative, and lipophilic compounds?" In an editorial entitled, "A Sluggish Response to a Smoldering Problem," Reddy (2005) asks why PBDEs are used despite all of the data and scientific knowledge that has been available for decades. If persistence and bioaccumulation were used to screen for potential hazards, then the size and seriousness of future "surprises" could be reduced. However, less than 10 percent of high-volume industrial chemicals have been evaluated regarding their bioaccumulation, environmental fate, and toxicity.

A much more precautionary, responsive, and democratic approach is clearly required. Thornton (2000) identified several reasons why the current risk paradigm is inappropriate for the regulation of chemicals—particularly persistent, bioaccumulative chemicals—on a global scale (Table 3).

Table 3.
Limitations of Current Risk Paradigm for Chemical Regulation

Risk Assessor's World	The Great Lakes
Assumes a well-characterized, linear system where probabilities of individual events can be added or multiplied to yield the probability of an overall outcome, and where uncertainties can be defined and quantified.	Living organisms and ecosystems are complex, unpredictable, interconnected, and hierarchical. Characterized by multifactorial causality, redundancy, multiple functions, and critical periods of high sensitivity. Scale effects are common in living systems. These systems are not well understood or characterized. There is much uncertainty and even greater ignorance. Reliable predictions are therefore impossible and illusionary.
Assumes impacts are local and immediate.	Chemicals enter water, atmosphere, and biota, and are very mobile. Therefore a "local scenario" is inadequate. The effects of chemicals may not be immediate, but depend on bioaccumulation or a particular combination of stresses. Effects may be transgenerational.
Assumes that living things can absorb and eliminate synthetic chemicals.	Individual organisms and the Great Lakes ecosystem have limited capacity to cope. Chemicals accumulate in media and often bioaccumulate in organisms.
Assumes exposure to one chemical at a time.	Organisms and ecosystems are chronically exposed to a complex and variable cocktail of synthetic chemicals, which is usually poorly characterized.
Requires adequate and appropriate data.	Adequate data are lacking for the majority of chemicals in commerce. Industry's capacity to invent and produce new chemicals has overwhelmed both their ability to produce adequate data for the regulatory system to assess, and the regulatory system's capacity to assess it.
Frequently recommends "end-of-pipe" approaches of control and disposal.	These approaches at best reduce contamination. They transfer substances from one form to another and from one location to another. Little is actually eliminated.

Human-health effects associated with contaminants in fish include a range of serious health consequences involving neurodevelopmental, reproductive, carcinogenic, respiratory, behavioural, and circulatory systems.

It is difficult for decision makers to make wise decisions when environmental or health impacts may occur far into the future. The costs of impact-averting decisions are large and immediate. Prevention usually requires acting before there is strong proof of harm, particularly if the harm may be delayed and irreversible. This protective approach to scientific evidence and policy making is part of the Precautionary Principle. One task of the European Environmental Agency (EEA) is to provide information to improve decision-making and public participation in regard to toxic compounds and their use in commerce. The EEA gathers information on the hazards of human activities and uses it to propose actions to better protect the environment and the health of species and ecosystems that are dependent on it. The process provides information in situations of scientific uncertainty.

The issues associated with "legacy" and "emerging" contaminants of concern and the contaminant-associated health effects described in this chapter are, to varying degrees, surprises, in that they highlight the short-sightedness of our profit-driven approach to innovation, and the inadequacy of our hazard-based regulatory system. They illustrate that having sufficient information and acting wisely for the wide range of environmental and health issues are a daunting task. The interconnections among issues, the pace of technological change, our limited understanding of effects, and the "time to harm and then to heal" ecological and biological systems affected over decades by our technologies present an unforgiving context (Beltran in EEA 2001). They also present immense and exciting challenges, and opportunities to understand the system and meet human needs while greatly reducing ecological and health costs. Other jurisdictions widely apply the Precautionary Principle to stimulate innovation and science, and provide good governance.

In trying to reduce current risks and future surprises, the lessons of history have rarely been used. The EEA's publication, *Late Lessons from Early Warnings: The Precautionary Principle 1896-2000* (EEA 2001) is an exception. Fourteen case studies are presented representing a variety of well-known hazards to workers, the public, and the environment, where sufficient information is now known about their impacts to enable conclusions to be drawn about how well they were dealt with by governments and civil society. The cases include collapsing fisheries, mad-cow disease, radiation, a variety of chemicals and drugs, growth promoters, and chemical contamination of the Great Lakes. The cases consider "false negatives," agents or activities that were regarded at one time as harmless by governments and others at prevailing levels of exposure, and "control," until evidence about harmful effects emerged. From the cases, 12 lessons were distilled (Table 4).

Table 4.
Twelve Lessons to Guide Sound and Effective Policies to Minimize Future "Surprises"

- Respond to ignorance as well as uncertainty
- Research and monitor for "early warnings"
- Search out and address "blind spots" and gaps in scientific knowledge
- Identify and reduce interdisciplinary obstacles to learning
- Ensure that real-world conditions are fully accounted for
- Systematically scrutinize and justify the claimed "pros" and "cons"
- Evaluate alternatives and promote more robust, diverse, and adaptable solutions
- Use "lay" and local knowledge as well as all relevant specialist expertise
- Take account of wider social interests and values
- Maintain regulatory independence from economic and political special interests
- Identify and reduce institutional obstacles to learning and action
- Avoid "paralysis by analysis" by acting to reduce potential harm when there are reasonable grounds for concern

A new approach to chemical regulation is required that incorporates these lessons. Thornton (2000) proposed an ecological paradigm to prevent global chemical pollution built around four principles:

- Zero discharge;
- Reverse onus (one could add Responsible Care and Product Stewardship);
- Emphasis on classes of compounds; and
- Clean production.

5.15 Conclusions

A number of strategies have been identified to address concerns related to new and emerging contaminants. They include:

- Work with industry to develop and implement cost-effective strategies that reduce ongoing releases to the environment from consumer products that enter waste streams;
- Require a basic information package that includes the octanol/water partition coefficient and that persistence data be made available for all compounds;
- Systematically monitor concentrations in human blood and breast milk, sport fish, and fish-eating birds;
- Support research on the health effects of these chemicals in fish, fish-eating wildlife, and humans at environmentally relevant concentrations, singly and in mixtures;
- Formalize and adequately fund programs that monitor health effects in humans, fish, and wildlife;
- Provide appropriate funding to investigate the effects of pharmacologically and hormonally active chemicals in fish and fish-eating wildlife at environmentally relevant concentrations;
- Develop cost-effective strategies for collecting and destroying unused or expired medications, and for reducing and treating waste streams from hospitals;
- Introduce labeling programs for PPCPs that enable consumers to make environmentally friendly choices concerning use and disposal; and
- Assess the impact of contaminants in biosolid and liquid-manure applications to agricultural lands in terms of exposure and effects on terrestrial wildlife.

There are a wide variety of transport pathways by which "emerging" chemicals enter and persist in surface waters. Some compounds, such as pesticides, are intentionally released in measured applications. Others, such as industrial by-products, are released through regulated and unregulated industrial discharges to water and air. Some are deposited in precipitation. Household chemicals, pharmaceuticals, and other consumables as well as biogenic hormones are released directly to the environment after passing through wastewater treatment plants or domestic septic systems, which often are not designed to remove them from the effluent. Veterinary pharmaceuticals and growth-promoting hormones used in animal feeding operations may be released to the environment with animal wastes through surface runoff, overflow, or releases from storage structures or land application.

Municipal wastewater treatment plants discharge much of the PFOS, PPCPs, synthetic estrogens, and estrogenic alkylphenols entering the Great Lakes. Most removal of these chemicals from wastewater occurs during advanced treatment. To be more effective, medium- and larger-sized sewage plants must be upgraded to incorporate secondary biological treatment with retention times of greater than 15 hours, as well as nitrification combined with denitrification. Tertiary treatment processes such as activated carbon filtration, ozonation, and membrane filtration will further reduce—but not eliminate—the loads of these "emerging" chemicals into the lakes.

Great Lakes success in environmental management to date is largely based on regulation and control programs. The concentrations of targeted chemicals such as PCBs have decreased markedly since regulations were introduced, but current rates of decrease are very low because regulation does not address the legacy sources—contaminated sediments. To eliminate the need for fish consumption advisories, cleanup of PCB-contaminated sediments and a 90 percent reduction of mercury emissions from U.S. coal-fired power plants within the next 10 years are required.

Meanwhile, concentrations of new classes of persistent toxic contaminants such as BFRs and PFCs are increasing rapidly in tissues of humans, wildlife, and fish. Laboratory studies suggest some "emerging" contaminants have toxicities and modes of action similar to "legacy" contaminants. Precautionary regulatory actions effectively reduce exposure to "emerging" chemicals. For example, concentrations of brominated diphenyl ether 47 are now declining in breast milk in Sweden (Bergman, presentation at Brominated Flame Retardants 2004). Germany's precautionary actions to reduce exposure to alkylphenols are already reflected in declining concentrations in fish (Wenzel *et al.* 2004). Kirby *et al.* (2004) have shown a striking relationship between the introduction of secondary treatment at the Howden sewage-treatment plant on the River Tyne with the reduction of mean estrogenic potency of the effluent from 80 to 0.4 ng/L and the reduction in plasma vitellogenin in male flounder caught near the outfall.

Since consumption of many "emerging" chemicals is expected to increase as populations grow and age, a proactive, precautionary, cost-effective control strategy must focus on reduction, minimization, and elimination at the source. This includes:

- Separate and appropriate treatment for hospital and industrial wastewater, and treatment of effluents from concentrated animal-feeding operations;
- Regulations to ensure that unused, expired pharmaceuticals are collected and appropriately destroyed under controlled conditions; and
- Environmental labeling introduced in cooperation with industry.

In this biennial cycle it became clear that our understanding of health hazards associated with "legacy" contaminants has increased much more rapidly than their levels are currently decreasing. PCB and mercury levels in fish are many times greater than values protective of human health. PCB concentrations in fillets of some large lake trout from Lake Michigan exceed by 40 fold the level which would allow unrestricted consumption. Despite consumption advisories, many individuals are exposed unnecessarily, and often unconsciously, to toxic contaminants through their diet. We have also learned that air transport is an important pathway of exposure and that living near highly contaminated areas increases one's exposure. In addition, we have become aware of "emerging" chemicals that were not previously detected. There is also a growing awareness of a larger range of developmental and functional health impacts associated with exposure to mixtures of chemicals, including the persistent "legacy" contaminants and the "emerging" chemicals. It is now clear that a single chemical can have an impact on multiple-organ systems via several exposure pathways and a number of modes of action, and that those impacts can be expressed in multiple ways. Many "emerging" chemicals affect the same target organs and/or systems as the "legacy" chemicals and will contribute to the cumulative toxicity. What evidence of human-health effects will be sufficient to create the political will to clean up the areas that continue to make major contributions to system contamination?

If sufficient resources to support remediation and required protection efforts are to be committed, Great Lakes citizens must understand the risks and demand accountability under the Agreement for long-term progress and implementation strategies that are protective of human and wildlife health and 20% of the world's fresh surface water.

> The need for improving overall coordination of Great Lakes, coastal, and ocean activities has been emphasized repeatedly in recent years ...

5.16 Recommendations

The Science Advisory Board recommends to the IJC that:

- **The Parties target brominated flame retardants, perfluorinated alkylsulfonates (and their salts), and alkylphenols as Level 1 substances under the Binational Toxics Strategy in order to achieve their policy of virtual elimination of the discharge of persistent toxic substances.**
- **The Parties invest in strategies to detect and mitigate the environmental effects of new and emerging contaminants.**
- **The Parties' Binational Executive Committee adopt a binational approach to the use of the precautionary principle in the management of chemicals in the Great Lakes basin.**
- **The Parties accelerate the removal of severely contaminated sediment from Areas of Concern.**
- **The Parties modify their fish consumption advice to address overall fish consumption to focus on:**
  - **Developing a single advisory that addresses both lipid-soluble contaminants such as PCBs, dioxins, and pesticides as well as methylmercury;**
  - **Providing readily accessible information that is linguistically, culturally, and economically appropriate;**
  - **Reaching the most vulnerable populations;**
  - **Promoting special precautions for pregnant women including effects on the fetus, women of child-bearing age, and children under 15, and advocating that this group adopt the additional prudence of not eating Great Lakes fish as an option; and**
  - **Providing information on nutritionally equivalent alternatives to fish.**
- **The Parties conduct a thorough and transparent benefit-cost analysis of mercury emissions to the Great Lakes environment, including impacts on the health of humans and wildlife, lost economic activity to sport and commercial fishing, as well as the costs of controlling emissions from coal-fired power plants, chloralkali plants, and other sources and remediating mercury contamination.**
- **The Parties undertake human health-effects research focusing on multi-media exposure due to place of residence, with consideration of non-cancer effects such as heart and respiratory disease, diabetes, and endocrine, reproductive, and neurological disorders.**

5.17 Appendix – Emerging Contaminants of Concern

5.17 1 Brominated Flame Retardants

Name

Polybrominated diphenyl ethers (PBDEs), hexabromocyclodecane (HBCD), tetrabromo bisphenol A (TBBPA), bis(2,4,6-tribromophenoxy)ethane (BTBPE)

Use and Sources

PBDEs are manufactured in three mixtures. The penta-BDE mixture is used almost entirely on polyurethane foam in upholstered furniture. The octa-BDE mixture is used exclusively in plastic resins for electronic housings. Deca-BDE is primarily used in thermoplastics for electronic equipment housings (TVs and computers), and smaller amounts are used to flame retard upholstery textiles. PBDEs are "additive" flame retardants and are blended with, rather than covalently bonded into, the product. They can comprise as much as 50 percent by weight of foam cushions. Global demand for PBDEs in 1999 reached 67,125 tonnes, near the PCB production maximum in 1970.

HBCD is the most widely used brominated fire retardant (BFR), at around 16,000 tons per year. HBCD is added to polystyrene foams that are used as thermal insulation in the building industry. Lesser amounts are used in upholstery textiles for furniture and transportation seating, and in draperies and wall coverings. It is considered a replacement for PBDEs.

TBBPA is another high-volume BFR widely used in paper products, clothing, upholstery, carpets, and other household materials. It is also found in resins, polycarbonates, and other plastics used to make computers, the housing for other electronics such as telephones, appliances, circuit boards, and many other consumer products. Worldwide, this is the most used BFR.

BTBPE is used in high-temperature plastics.

BFRs slowly volatilize into the environment during the treated product's lifetime. Concentrations in indoor air are much greater than outdoor air (Wilford *et al.* 2004). The large amounts in residential-use products suggest that the home environment is a significant source of human exposure. High concentrations of PBDEs have been measured in house dust and clothes dryer lint (Stapleton *et al.* 2005), particularly of congeners associated with the penta- and deca-BDE mixtures.

Urban indoor air is a source to urban outdoor air, which is a source to the regional environment (Butt *et al.* 2004, Shoeib *et al.* 2004). Currently PBDE concentrations equal or exceed those of PCBs in rural Ontario air.

Thus, large reservoirs exist of the penta-BDE mixture and other BFRs in the form of treated products (cars, upholstered furniture, carpets, and electronics), which will serve as sources for years to come. Environmentally friendly methods of disposal of polyurethane foam, cars, upholstered furniture, carpets, TVs, and computers must be found and practiced.

History

PBDEs were introduced in 1972 to replace PCBs. By 1986, a voluntary phase-out was initiated in Germany, followed by legislation to restrict their use in 1993. Swedish chemists reported that PBDEs had doubled in human breast milk every five years since their introduction in 1972 (Darnerud *et al.* 1998, Noren and Meironyte 2000). Sweden proposed a phase-out by March 1999.

Penta-BDEs are being considered a "potential/candidate" under the United Nations Economic Commission for Europe's persistent organic pollutant convention. Great Lakes Chemical Company, the sole producer of penta-BDE in the U.S., chose to phase out production by the end of 2004. The European Union phased out the use of the penta- and octa-BDE mixtures in 2005 and California will do so in 2008.

The United Kingdom's Chemical Stakeholder's Forum determined that HBCD is persistent, bioaccumulative, and toxic, and poses a risk to the environment.

Properties

PBDEs are persistent, hydrophobic, lipophilic, bio-accumulative, and subject to long-range transport. They have a greater tendency than PCBs to adhere to particles that are washed out of the atmosphere by precipitation.

Current Concentrations

See Table 2. It is estimated that approximately 15 million people in the U.S. have lipid PBDE levels greater than 300 parts per billion.

Concerns

Residues of PBDEs are ubiquitous in the global environment. In North America, tissue concentrations are doubling every two to five years in fish, whales, birds, and humans (Hites 2004, Lebeuf 2004). The doubling time in human tissues in North America is shorter than in Europe and Japan, where tissue concentrations are less than one-tenth of those measured in North America. If present rates of change continue, total BDE concentrations will surpass those of PCBs in gull eggs and lake trout tissues within a decade. Norstrom *et al.* (2002) found that penta-BDE, which is mainly used in polyurethane foam, was responsible for the rapid increase in overall concentration in gull eggs. Dramatic increases in PBDE concentrations toward the surface of sediments are evident in Great Lakes sediment cores (Song *et al.* 2005).

In a study conducted in Indiana, the concentrations of PBDEs in maternal and fetal-blood samples were very similar (Mazdai *et al.* 2003), confirming that PBDEs cross the placenta. Structurally, PBDEs are similar to the thyroid hormone thyroxin. Like PCBs, each PBDE congener exhibits different potency and toxicity. Chronic administration of PBDE congeners during lactation (neonatally) to rodents revealed thyroid and estrogenic effects similar to some PCBs (Zhou *et al.* 2002), and altered expression of estrogen-regulated genes in the prostate and the brain (Lichtensteiger *et al.* 2003). Rodent studies revealed altered spontaneous behavior (Eriksson *et al.* 2002), learning and memory difficulties that became worse with age (Viberg *et al.* 2003), as well as hearing loss, delayed puberty, and increased ventral prostate and seminal vesicle weight gains in males (Stoker *et al.* 2004), and delayed puberty in females (Laws *et al*. 2003). The additive effect of PBDEs with co-exposure to PCBs increases concerns about their impacts on development of the brain and reproductive system. The presence of PBDEs in household products makes indoor-air exposure a pathway of concern, especially for infants and small children.

When American kestrel eggs were injected with a mixture of penta-BDE congeners and the hatchlings fed a diet containing the same mixture at environmentally relevant concentrations, T-cell mediated immunity and relative bursal mass were inversely associated with BDE-47 (Fernie *et al.* 2005). There were also structural changes in the spleen, bursa, and thymus. These exposures also altered thyroxin and vitamin A homeostasis and induced oxidative stress (Fernie *et al.* in press). In *in vitro* assays using lake trout thymocytes, BDE-47 markedly reduced thymocyte viability, increased apoptosis and necrosis at 100 mg/L, whereas the effects of BDE-99 were minor at this concentration (Birchmeier *et al.* 2005).

HBCD is bioaccumulating and biomagnifying in the Lake Ontario food chain at a rate similar to DDE and PCBs (Tomy *et al.* 2004). Very little is known about its toxicity, and nothing is known about the toxicity of BTBPE, which is a modified diphenyl ether.

5.17.2 Perfluorinated Acids, Alcohols, and Salts

Name

The compounds of concern include N-ethyl perfluorooctane sulfonamidoethanol (N-EtFOSE), the acrylate polymer and parent compound of perfluorooctane sulfonate (PFOS, Scotchgard®), and aqueous film-forming foams such as Light Water Line®. N-EtFOSE eventually breaks down into two end products widely found in the environment, PFOS and perfluorooctanoic acid (PFOA). The fluorinated compounds also include polytetrafluoroethylene (PTFE or Teflon®).

Use and Sources

Approximately 14.3 million pounds of perfluoronated chemicals (PFCs) were produced in 2002. N-methyl perfluorooctane sulfonamidoethanol (N-MeFOSE, Scotchgard®) was used for surface treatments of apparel, leather, upholstery, carpet, and auto interiors, and on paper products such as plates, bags, food wraps, and masking paper. N-EtFOSE (Scotchban®) and PTFE are used in the production of industrial coating applications, fire-fighting foam, lubricants in aeronautical systems, industrial surfactants, floor polishes, photographic film, denture cleaners, shampoos, and floor finishes.

Environmental sources are largely uncharacterized. Direct sources are aqueous film-forming foams and indirect sources through abiotic or biotic degradation of products used in surface treatment applications. Concentrations in indoor air are significant and about 100 times those in outdoor air (Shoeib *et al.* 2004), suggesting that they originate in releases from products present in homes and businesses. Despite manufacturing phase-outs, these products will serve as a continuing source throughout their lifetimes, and exposure is greater in more urbanized areas than in more remote areas. Mass balance studies on Lake Ontario revealed that the greatest source of N-EtFOSE and PFOS was from municipal wastewater effluent discharges (Hornbuckle, presentation). PFOS in effluents comes directly from consumer products through sewage systems. PFOS was found in household vacuum cleaner dust at 3.7 ppm (Moriwaki *et al.* 2003). A survey of sewage sludges from wastewater treatment plants in the San Francisco Bay area revealed concentrations of 55 to 3370 ng/g for total PFOS-based chemicals (Higgins *et al.* 2005).

History

PFOS and related PFCs had been manufactured by 3M Company since 1948. Due to concerns about biopersistence and widespread exposure to wildlife and humans, 3M announced in 2000 that it would voluntarily cease production of PFOS-based chemicals as of December of that year. The U.S. Environmental Protection Agency (EPA) immediately proposed legislation that would regulate new uses of PFOS and related chemicals. In 2001, Kannan *et al.* confirmed widespread contamination in humans and wildlife over large geographic areas. In 2004, Environment Canada released a Draft Screening Assessment that concluded PFOS, its salts, and its precursors are "toxic" under Paragraph 64(a) of the 1999 Canadian Environmental Protection Act (CEPA), and recommended that they be considered for virtual elimination under subsection 65(3). Sweden proposed a ban to eliminate PFOS under the Stockholm Convention.

Properties

PFCs have unique physical, chemical, and biological properties. They are both lipophobic and hydrophobic. They do not accumulate in lipid-rich tissues, but bind to proteins and accumulate in the liver and blood. Their high-energy, carbon-fluorine bond renders them resistant to all known forms of abiotic and biotic degradation. In laboratory tests, bioconcentration of PFCs increases with carbon-chain length. In mink that were fed Saginaw Bay carp containing a mean of 120 ng/g, the mean biomagnification factor was 18, similar to that of PCBs in the same study (Kannan *et al.* 2002). However, a bioconcentration factor range of 6,300 to 125,000 was calculated for PFOS based on concentrations in fish liver and surface water following an accidental spill of perfluorinated surfactant-containing fire retardant foam (Moody *et al.* 2002).

Current Concentrations

See Table 2. In humans, 645 adult donor serum samples from six American Red Cross blood-collection centers had a geometric mean PFOS concentration of 35 ng/ml (4 to 1,656), somewhat higher in males than females, but no substantial difference with age (Olsen *et al.* 2003).

Concerns

Organofluorine residues in wildlife tissues suggest they are globally distributed (Giesy and Kannan 2002). PFOS concentrations doubled every twelve years between 1980 and 2001 in archived lake-trout tissue from Lake Ontario (Martin *et al.* 2004). Boulanger *et al.* (2005) highlight the need for monitoring studies to identify wastewater treatment plants with unusually high concentrations of PFCs in their effluent so that remedial actions can be taken.

Related fluorochemicals have been shown to affect cell-to-cell communication, membrane transport, and the process of energy generation. PFOS and PFOA exhibit multi-system, low-dose toxicity, driven by several mechanisms including mitochondrial activity, peroxisome proliferation, inhibition of thyroid hormones, and increased serum estradiol as a result of liver aromatase induction (Thayer, presentation).

Exposure of rats and mice to PFOS during pregnancy at concentrations of 1 to 20 mg/kg resulted in maternal (weight loss, decreased thyroxine, reduced triglycerides) and developmental toxicity (birth defects) in both species (Thibodeaux *et al.* 2003), compromised neonatal survival, and caused delays in growth and development that were accompanied by hypothyroxinemia in the surviving rat pups (Lau *et al.* 2003). U.S. EPA has raised concerns about the long residence time of PFOS in humans, high blood concentrations, and the possibility of developmental risk to fetuses and children. Little is known about the toxicity of PFOS in wildlife.

5.17.3 Phthalates

Name

Diethylhexylphthalate (DEHP), butylbenzylphthalate (DBP), and di-n-butylphthalate

Use and Sources

Phthalates are produced in extremely large volumes and their use is increasing. Production of DEHP, the most widely used phthalate, amounts to 400,000 to 500,000 tons per annum in Europe alone. Phthalates are found in soft plastics and packaging, cosmetics (up to 50 percent by weight), insecticide sprays and repellants, carpeting, wood finishes and paints, coating on time-release capsules, vinyl flooring, adhesives, sealants, car-care products, inks, and medical equipment. Since phthalates are not covalently linked to the plastic polymer, they leach out into the environment. It has been estimated that one percent of phthalates used are eventually lost to the environment (ECPI 1996).

History

Phthalates have been used in plastic and other products for a long time.

Current Concentrations

Phthalates are ubiquitous. However, for decades analytical challenges prevented an accurate assessment of their concentrations. Today, modern instrumentation and "clean" laboratory procedures permit their measurement, but few data are available.

In a nationwide survey of phthalates in stream-bed sediments (Lopes and Furlong 2001), the western Lake Michigan drainage was among those sites with the highest concentrations (sum approximately 850 ppm). High concentrations were found in urban and industrialized regions and in large metropolitan areas. DEHP, DBP, and di-n-butlyphthalate were the most frequently found in environmental samples.

Eight phthalates were detected in dust from 86 to 100 percent of households with maximum concentrations ranging from 31,000 ng/g (DBP) to 7,700,000 ng/g (DEHP) (Rudel *et al.* 2003). These same phthalates were detected in air samples from 15 to 100 percent of the same households, with median DEHP (530 ng/m^3, 130 to 4300) and DBP (220 ng/m^3, 52 to 1100) concentrations being the highest. These data suggest indoor air is an important exposure vector.

Concerns

Phthalates are of concern because they accumulate in the environment and human blood, have numerous exposure vectors, and act as endocrine disruptors in rodents. Some, including DBP and DEHP, are weakly estrogenic *in vitro* (Harris *et al.* 1997). They are testicular toxins (Gray and Gangolli 1986), reproductive teratogens (Barlow and Foster 2003) and embryo toxins, and anti-androgens (Mylchreest *et al.* 2000, Fisher 2004). Among the phthalates, DEHP is the most potent anti-androgen (Gray *et al.* 2000).

In a multigenerational reproductive toxicity study, Wine *et al.* (1997) found that several reproductive parameters were adversely affected by exposure to DBP in food, and that the second generation appeared more adversely affected than the first in that most of the F1 males were infertile. Prenatal phthalate exposure has been associated with shortened anogenital distance in boys (Swan *et al.* 2005). Anogenital distance was correlated with penile volume and the proportion of boys with incomplete testicular descent. These associations between male genital development and phthalate exposure are consistent with the phthalate-induced incomplete virilization observed in prenatally exposed rodents (Gray and Foster 2003).

Monoethylphthalate (MEP) was found 100 percent of the time in the urine of 2,540 human subjects at a geometric mean concentration of 179 ppb (Silva *et al.* 2004). MEP in human urine has been associated with alterations and increased DNA damage in sperm (Duty *et al.* 2003a, b). Exposure to monobutylphthalate is associated with reduced sperm motility and velocity (Swann *et al.* 2005).

5.17.4 Pharmaceuticals, Personal Care, and Household Products

Low levels of reproductive hormones, steroids, antibiotics, pain killers, contraceptives, beta-blockers, lipid regulators, tranquilizers, anti-epileptics, serotonin re-uptake inhibitors, and numerous other prescription and non-prescription drugs, as well as some of their metabolites, have been detected in surface waters. Along with pharmaceuticals, products used in everyday life such as detergents, disinfectants, fragrances, insect repellents, fire retardants, and plasticizers are turning up in the aquatic environment. Effluents from concentrated animal feeding operations contain antibiotics and growth-promoting hormones. Little is known about the toxicity of these "emerging" contaminants at low levels and on non-target organisms, particularly hormonally active chemicals, pesticides, and pharmaceuticals that are designed to stimulate a response in humans, animals, and plants. It is difficult to predict what health effects they may have on humans and aquatic systems (Erickson 2002), and they always occur in a complex mixture.

Exposure

During and after treatment, humans and animals excrete a combination of intact and metabolized pharmaceuticals in the form of bioactive metabolites. Personal care products do not have to pass through the human body, but enter wastewater directly after their use. Wastewater treatment plants are likely to be the most significant conduit of human medications to surface waters, while application of contaminated livestock manure may also contribute a high load of veterinary drugs to the aqueous phase of runoff events. Sewage is a continuous point source, while runoff from agriculture is diffuse and concentrations are dependent on the application rate and runoff parameters.

Pharmaceuticals were reported in Lake Ontario and Lake Erie surface waters in 2000 and in final effluents from wastewater treatment plants on the Detroit and Niagara Rivers in 2001. They included Carbamazepine (an anti-epileptic) at 0.65 ug/L, naproxen and ibuprofen (anti-inflammatories), and several lipid-regulating drugs found below three wastewater treatment plants. Concentrations remained constant as far as 100 metres downstream. Fluoxitine (Prozac®) was found in the final effluent at three out of four locations as high as 0.099 ug/L, and in downstream surface water (Metcalfe, presentation).

Koplin *et al.* (2002) measured 95 organic wastewater contaminants in water from 139 streams across 30 states in 1999 to 2000; 82 were found at least once, and 80 percent of the streams contained two or more. As many as 38 contaminants were measured in a single sample, with a median of seven. The most frequently encountered were diethyltoluamide (an insect repellent), caffeine (a stimulant), triclosan (antimicrobial disinfectant), tri (2-chloroethyl) phosphate (a fire retardant), and nonylphenol (NP) (non-ionic detergent metabolite). Three classes of compounds—the detergent metabolites, plasticizers, and steroids—had the highest concentrations.

Synthetic musks, used as fragrances in a variety of personal care products, are consistently found in municipal wastewater discharges (Simonich *et al.* 2002). More than one million pounds of one such compound, HHCB (Galaxolide), is produced or imported into the U.S. annually. It was estimated that 3,470 kilograms enters Lake Michigan in wastewater effluents each year (Peck and Hornbuckle 2004). Simonich *et al.* (2002) found a mean of 1,640 ng/L in 12 U.S. wastewater treatment plant effluents.

Concerns

For the most part these substances are not bioaccumulative, but their continual input into the environment ensures their persistence. By design, pharmaceuticals and pesticides are biologically active at the cellular-receptor level. Therefore, very low concentrations may be biologically significant. Potential concerns about the environmental presence and chronic low-level exposure to these compounds include abnormal physiological processes, reproductive impairment, teratogenicity, altered behavior, increased incidences of cancer, development of antibiotic-resistant microorganisms, and potentially increased toxicity and interactions of complex chemical mixtures and effects. In addition, the pharmacological target of a drug in mammals may be markedly different in fish and other organisms. For example, Propranolol is a potent inhibitor of photosynthesis by algae (Escher *et al.* 2005). Preliminary studies suggest prostaglandin-inhibiting analgesics frequently found in water are capable of altering reproductive function and behavior in fish (Miller *et al.* 1999, Stacey 1976), blood-lipid regulators alter their intermediary metabolism (Donohue *et al.* 1993, Haasch *et al.* 1998), and serotonin re-uptake inhibitors induce developmental abnormalities, increase plasma estradiol, and alter their migration behaviors (Brooks *et al.* 2003). Inui *et al.* (2003) found three common ultra-violet screens to be estrogenic to male Japanese medaka, a fish commonly used in toxicity testing. There is almost no information about the effects of mixtures of this vast array of compounds at environmentally relevant concentrations.

Triclosan exhibits antibacterial, antifungal, and antiviral properties and is therefore a very useful disinfectant. Its incorporation into toys, kitchen tiles, athletic clothing, and other products, coupled with its occurrence in surface water and wastewater treatment plant effluent, have raised concerns that they might promote microbial resistance.

Synthetic musks, including HHCB, bioaccumulate and have been found in top predators in marine food chains (Nakata

2005). In marine mammals there is evidence of transplacental transfer. Synthetic musks test positive in *in vitro* assays for estrogenic activity (Bitsch *et al.* 2002, Scheurs *et al.* 2004). Elevated levels of musks in women's blood have been associated with ovulation and premenstrual symptoms and in a dose-response manner with miscarriage (Eisenhardt *et al.* 2001).

5.17.5 Estrogenic, Androgenic, and Other Hormonally Active Compounds

Name

These compounds are called ethinyl estradiol, bisphenol A (BPA), Trenbolone, and alkylphenol ethoxylates (treated separately in the next section).

Use and Sources

Ethinyl estradiol, the potent synthetic estrogen present in birth-control pills, and 17-beta estradiol, the naturally produced female estrogenic hormone, are excreted in feces and urine and enter open waters via municipal sewage effluents. BPA is a building block in polycarbonate and other plastic resins and is used to line food containers, make baby bottles, high-impact sporting equipment, dental sealants, and shatterproof glass. It is also used in detergents to reduce re-deposition of dirt and has been found in wastewater from commercial laundries. Its production in the U.S. alone exceeds 800 million kilograms a year. The concentrations of 17-beta estradiol— the hormone normally excreted by premenopausal women— found in the environment can have disruptive effects on key steroidogenic enzyme pathways that control sexual development in fish (Halm *et al.* 2002).

Trenbolone and melengestrol are licensed to promote the growth of livestock in North America. The anabolic effect of Trenbolone is eight to ten times stronger than testosterone, while melengestrol is 125 times more potent than progesterone (Neumann 1976).

Concerns

Exogenous hormones modulate a system that is physiologically active, potentially above any response threshold that might exist. Ethinyl estradiol was found in surface waters across the U.S. in a recent survey (Koplin *et al.* 2002).

BPA has been found in raw sewage, sewage sludge, and final effluents across the continent. The median concentration in sewage sludge in 35 samples from across Canada was 0.45 ug/kg, with a maximum of 5 ug/kg (Environment Canada 2001). However, it has been found in the Mississippi River as high as 113 ppb and in storm-water channels at 158 ppb. BPA was detected in dust samples from 86 percent of 118 homes at a median concentration of 821 ng/g (range from less than 200 to 17,600 ng/g) (Rudel *et al.* 2003).

Trenbolone had a half-life in liquid manure of more than 260 days (Schiffer *et al.* 2001). Effluents from concentrated cattle feeding operations contain significant amounts of estrogenic and androgenic activity (Soto *et al.* 2004). Male fathead minnows were demasculinized and females defeminized in a stream receiving such effluent (Orlando *et al.* 2004). Laboratory exposures of fathead minnows to Trenbolone for 21 days altered female and male reproductive biology (Ankley *et al.* 2003). Fecundity was significantly reduced by exposure to concentrations greater than 27 ng/L.

The presence of estrogens in the aquatic environment has been intensively studied in the U.K., where they were associated with an elevated incidence of intersex in the gonads of fish (Jobling *et al.* 1998). Similar surveys in North America suggest that they are also present in biologically significant concentrations in surface waters (Koplin *et al.* 2002). Fish below sewage treatment outfalls have altered sex steroid ratios, abnormal reproductive organs and, upon prolonged exposure to the estrogens, the critical threshold of response is lowered (Jobling *et al.* 1998). Nichols *et al.* (1999) did not find any evidence of endocrine disruption in fathead minnows caged for 21 days near the outfalls of seven municipal WWTPs in central Michigan.

Metcalfe *et al.* (2001) used the Japanese medaka bioassay to determine the relative estrogenic potency of estrogen hormones, nonylphenol ethoxylate (NPEO) degradation products, BPA, and DEHP using the development of intersex gonads and altered sex ratio as end points. The lowest observed effect levels (LOELs) were 0.03 ng/L for ethinyl estradiol, 4 ng/L for estradiol, 8 ng/L for estrone, 31,000-47,000 ng/L for NPEO plus nonphenol diethoxylate, and 5,900 ng/L for BPA. The LOELs for the estrogen hormones and alkyphenol ethoxylates are within the range of concentrations reported for wastewater treatment plant effluents. Ethinyl estradiol induced vitellogenin in male rainbow trout at a concentration of 1.8 ng/L (Jobling *et al.* 1996). When zebra fish were exposed to an environmentally realistic concentration of ethinyl estradiol of 5 ng/L over multiple generations, there was a 57 percent reduction in fecundity in the F1 generation and complete population failure due to a lack of functional testes (Nash *et al.* 2004). Although these males lacked functional testes, they showed normal spawning behavior, a phenomenon that is likely to affect breeding dynamics and reproductive success of group-spawning fish (Nash *et al.* 2004).

In 2000, the prevalence of intersex gonads in white perch was 83 percent in fish from Cootes Paradise in Hamilton Harbour, 44 percent in fish from the Bay of Quinte, and 45 percent in fish from Lake St. Clair (Kavenagh *et al.* 2004), but was not observed in hatchery-reared white perch. Analysis of plasma of male white perch collected in Cootes Paradise in 2002 revealed high concentrations of vitellogenin (Kavanagh *et al.* 2004). Male snapping turtles from Cootes Paradise also show evidence of feminization (de Solla *et al.* 1998). In surveys conducted 2001-2003 in Canadian Areas of Concern on the lower Great

Lakes and the Detroit River, vitellogenin was detected in male fish, snapping turtles, and herring gulls at several locations (Fox, presentation).

When Japanese medaka were exposed from hatching to sexual maturity to an environmentally relevant concentration of 10 ng/L ethinyl estradiol, reproductive behavior and performance were suppressed and intersex gonads were induced in males (Balch *et al.* 2004). Male fish with intersex gonads were capable of reproductive behavior and fertilizing eggs. The adult fish also showed evidence of liver and kidney toxicity (both sexes) and testicular toxicity (Weber *et al.* 2004).

Significant estrogenic activity in the St. Lawrence River is associated with vitellogenin induction, delayed spermatogenesis, reduced sperm production and motility, and a high incidence of intersexuality in male spottail shiners (Aravindakshan *et al.* 2004a). When lactating female rats were gavaged with homogenates of spottail shiners from these affected populations, their male offspring had significantly decreased sperm production and motility, and other indicators of altered testicular function (Aravindakshan *et al.* 2004b). This is the first indication that xenoestrogenic contaminants may pass through the food chain and exert their effects on the male progeny of predators.

Humans and their developing fetuses are widely exposed to BPA (Ikezuki *et al.* 2002). There are more than 100 published studies showing adverse effects of low doses of BPA in a variety of experimental animals (Vom Saal and Hughes 2005). Exposure to low doses during fetal life accelerates post-natal growth and advances puberty (Howdeshell *et al.* 1999), stimulates mammary epithelium (Markey *et al* 2001), disrupts the development of the fetal prostate and urethra (Timms *et al*. 2005), alters maternal behavior in mice (Palanza *et al.* 2002), and causes an increase in serum thyroxine in rat pups and alters the expression of a thyroid hormone-responsive gene in their brains (Zoeller *et al.* 2005). Post-natal exposure to very low doses disrupts meiosis in mouse oocytes (Hunt *et al.* 2003) and an epidemiological study of Japanese women has shown a correlation between both polycystic ovarian disease and obesity with blood levels of BPA (Takeuchi *et al.* 2004).

5.17.6 Alkylphenols

Name

The alkylphenol ethoxylates most commonly found in the environment are nonylphenol ethoxylates (NPEOs) and octylphenol ethoxylates (OPEOs), and their parent structures nonylphenol (NP) and octylphenol (OP).

Use and Sources

The use of NP is greater than OP. NPEOs are high-volume chemicals used as detergents, emulsifiers, and wetting and dispersing agents in many sectors including textile processing, pulp and paper processing, steel manufacturing, oil and gas recovery, and power generation. They are also used in paints, resins and protective coatings, and pest control products, and are found in cosmetics and cleaning products, degreasers, and detergents used in institutional and domestic sectors (Environment Canada 2001).

NP and NPEOs enter the environment primarily via industrial effluents (textile mills and pulp and paper mills) and municipal wastewater treatment effluents (liquid and sludge). Mean concentrations of NP and OP of up to 37,800 and 23,700 ng/g, respectively, were detected in sediments near sewage treatment plants and industrial wastewater discharges in the Great Lakes region (Bennett and Metcalfe 1998). Alkylphenols can be accumulated by biota near sewage outfalls, but distribution is localized to areas close to the point of discharge (Bennett and Metcalfe 2000). Substantial concentrations of NP and lower-chain NPEOs are found in sludge from municipal wastewater treatment plants. The application of NP-containing sludge to agricultural land may result in potential exposure in terrestrial environments. In the biosolids (sludge) from ten of 11 municipal wastewater treatment plants in the U.S., NP concentrations ranged from 5.4 to 887 ug/g, with a mean of 491 ug/g (La Guardia *et al.* 2001). OP was detected in eight of 11 of the biosolids tested at concentrations ranging from less than 0.5 to 12.6 ug/g. NP concentrations ranged from 0.07 to 1,260 ug/g (dry weight) (30 sites), with a mean of 491 ug/g in sludge samples from municipal treatment plants from across Canada (Environment Canada 2001). NP and NPEOs were detected in the dust from 80 to 93 percent of the 118 households at maximum concentrations ranging from 8,680-49,300 ng/g (Rudel *et al.* 2003).

History

Environment Canada concluded that NP and its ethoxylates are "toxic" as defined in Section 64 of CEPA ("entering the environment in a quantity or concentration or under conditions that have or may have an immediate or long-term harmful effect on the environment or its biological diversity"). Norway banned the production, import, use, and distribution of NPEOs and OPEOs as of January 1, 2002.

Properties

The available literature suggests that the ability of NP and NPEOs to bioaccumulate in aquatic biota is moderate. Liber *et al.* (1999) measured a bioaccumulation factor of 87 for NP in bluegill sunfish in a littoral enclosure in northeastern Minnesota over a 20-day period.

Current Concentrations

See Table 2.

Toxicity

Chronic toxicity values (no-observed-effects concentrations) for NP are as low as 6 ug/L in fish and 3.9 ug/L in invertebrates. There is an increase in the toxicity of NPEOs with decreasing ethoxylate chain length.

NP and NPEO have been reported to cause a number of estrogenic responses in a variety of aquatic organisms. Their potency, however, is 100,000 less than estradiol. NP and NPEOs are found as complex mixtures in effluents and their combined estrogenic effects on aquatic organisms should be considered together. Exposure of sexually mature fathead minnows to NP at 1,600 to 3,400 ng/L for 42 days resulted in statistically significant effects on gonadal histology of males (Miles-Richardson *et al.* 1999), while concentrations as low as 50 ng/L have been observed to elevate plasma estradiol concentrations five-fold over background levels in males and females (Giesy *et al*. 1998). The lowest observed effects concentration for induction of testis-ova in Japanese medaka was 50,000 ng/L (Gray and Metcalfe 1997). In male rainbow trout, the lowest concentration to induce a significant increase in vitellogenin was 20,300 ng/L, and 54,300 ng/L significantly decreased testicular growth (Jobling *et al.* 1996). OP induced a significant increase in vitellogenin at 4,800 ng/L, but no effect was seen on testicular growth.

U.S. EPA estimated that 60 percent of the 6.9 million tons of biosolids generated in 1998 was land-applied (U.S. EPA 1999). They predicted that biosolid use would increase by 40 percent by 2010. The implications in terms of exposure to terrestrial organisms and contamination of surface waters have not been investigated. Scottish investigators have reported that near-term male fetuses of sheep pastured on land treated repeatedly with sewage sludge suffered from a major attenuation of testicular development and hormonal function (Paul *et al.* 2005). The liquid sludge applications contained a mean of 146 mg/kg NP (dry matter), 0.27 mg/kg OP, and 96 mg/kg DEHP (Rhind *et al.* 2002).

5.17.7 Atrazine

Use and Sources

Atrazine is a pre-emergent herbicide used on corn. The annual use in the U.S. Great Lakes basin was estimated at 2,700 tonnes (U.S. General Accounting Office 1993).

History

Introduced in Canada in about 1960, it was subsequently found infrequently and at high concentrations in surface waters (Bodo 1991). Lower application rates were introduced in 1993.

Prevalence and Concentrations

In more than 490 surface water samples from 29 locations representing all five Great Lakes from 1990 to 1993, Schottler and Eisenreich (1994) detected Atrazine in all samples with mean concentrations, by lake, ranging from 3 to 110 ng/L. The highest concentrations were measured in Lake Erie, the lowest in Lake Superior. Between 1994 and 2000, Environment Canada measured 39 in-use pesticides in large-volume surface water samples collected at multiple stations in two or three years, in lakes Erie, Ontario, Huron, and Superior (Struger *et al.* 2004). The number of pesticides detected ranged from 32 in Lake Erie to four in Lake Superior. The maximum concentrations of all pesticides occurred in samples from Lake Erie. Atrazine occurred in 97 percent of the samples, with a maximum concentration of 1,039 ng/L. Recent surveys by Environment Canada found a maximum concentration of 4,900 ng/L in eight tributaries to Lake Erie, and 450 ng/L in eight tributaries to Lake Ontario (Struger, personal communication).

Concerns

Of the pesticides surveyed, Atrazine is the most prevalent and most concentrated. In the early 1990s, the estimated inventory of Atrazine in the waters of the Great Lakes was in excess of 600,000 kilograms with an estimated water column residence time in the order of years (Schottler and Eisenreich 1994).

Atrazine is an antiandrogen (Sanderson *et al.* 2001). The sex ratio of *Daphnia magna*, the water flea, shifts to males exposed to Atrazine at 0.5 ng/L (Dodson *et al*. 1999). Exposure during amphibian larval development induced hermaphroditism and abnormal gonadal development at 100 ng/L, and demasculinized the larynx of males at 1,000 ng/L by inducing aromatase, which converts testosterone to estrogens (Hayes *et al.* 2002). When leopard frog (*Rana pipiens*) larvae were exposed to 100 ng/L of Atrazine under controlled laboratory conditions, 36 percent suffered from gonadal dysgenesis and an additional 29 percent showed various degrees of sex reversal (Hayes *et al.*2003). In the field, sex reversal was encountered in males in all collections where Atrazine concentrations exceeded 200 ng/L (Hayes *et al.* 2003). Reeder *et al.* (1998) found an association between intersexuality and Atrazine exposure in wild cricket frogs (*Acris crepitans*) in Illinois. There is evidence that Atrazine potentiates parasitic trematode infections, which result in amphibian deformities (Kiesecker 2002). Atrazine has been associated with decreases in dissolved oxygen, pH, and phytoplankton, periphyton, and macrophytes, which are important food sources of larval amphibians and fish (Diana *et al.* 2000).

Applied as a pre-emergent herbicide, Atrazine contamination of water sources peaks with spring rains and coincides with amphibian breeding activities, as many amphibians reproduce during early spring rains. Atrazine concentrations in precipitation collected over the Great Lakes in May 1995 were greater than 1000 ng/L (Environment Canada 1996). Amphibians breed in a wide range of freshwater habitats including temporary pools, flooded fields, irrigation ditches, streams, rivers, lakes, and other permanent sources of water. Maximum concentrations in tributaries and precipitation occur from April to July, the peak period of larval development of amphibians in the Great Lakes basin. Given the proven sensitivity of amphibian larvae to Atrazine, and the evidence of widespread contamination at concentrations exceeding those known to cause sensitive developmental effects, it is highly probable that Atrazine is affecting amphibians in the vicinity of Lake Erie. Two of these species — Blancher's cricket frog (*Acris crepitans blanchardi*) and Fowler's toad (*Bufo fowleri*) — are currently considered at risk and listed under the Species at Risk Act.

5.18 References

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Chapter Six

GREAT LAKES SCIENCE ADVISORY BOARD

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Chapter Six

GREAT LAKES SCIENCE ADVISORY BOARD

6.1 Introduction

The Great Lakes Science Advisory Board (SAB) is a joint U.S. and Canadian institution established under the Great Lakes Water Quality Agreement to serve as the scientific advisor to the International Joint Commission (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."

SAB members include 18 eminent scientists appointed by the IJC, nine from each country. Their expertise comprises a number of scientific disciplines drawn from the social, physical, and natural sciences. As a board, these experts provide a multi-disciplinary perspective on scientific matters affecting progress under the Agreement. The members are drawn from universities, government institutes and agencies, and private industry, and serve on the SAB in their personal and professional capacities.

To provide advice on a wide range of issues, the SAB is organized into three work groups: the Work Group on Ecosystem Health; the Work Group on Parties Implementation; and the Work Group on Emerging Issues. Each is responsible for contributing scientific advice salient to priority topics assigned by the IJC. The identification and approval of biennial priorities by the IJC establishes topics, assigns lead responsibility to address them, and commits resources in support of the activity. Their involvement ensures that science-based advice remains the hallmark and focus of IJC activities under the Agreement.

For the 2003-2005 biennial cycle, the IJC committed to investigate and report on six broad Great Lakes priorities: advice on the review of the Agreement, land use, climate change, human health, mercury, and Annex 2 review and assessment. Only climate change and Annex 2, topics previously addressed by the SAB, did not involve the SAB during this biennial cycle.

The SAB is not restricted to providing scientific advice only for priority issues approved by the IJC. It may also provide independent advice and updates to the IJC on any scientific topic, such as emerging issues or as new scientific knowledge redefines old issues.

6.2 Board Activities in 2003-2005

In the 2003-2005 biennial cycle, the SAB comprehensively reviewed the adequacy of science under the 1987 Agreement. Specifically, each work group undertook a major activity on behalf of the SAB in relation to (1) the impact of urbanization on Great Lakes water quality (Work Group on Parties Implementation), (2) chemical exposures and effects (Work Group on Ecosystem Health), and (3) science-based approaches to Great Lakes water management through institutional arrangements and governance (Work Group on Emerging Issues). In addition to these major activities, the work groups also addressed emerging chemicals, provided an update on new scientific findings on mercury, and conducted an assessment of new scientific approaches for managing pathogens and microorganisms. These topics provide the basis for the SAB's scientific advice to the IJC during the 2003-2005 biennial cycle.

6.3 Overview

6.3.1 Urban Land Use (Full report in Chapter Four)

Land-use impact on the Great Lakes system is central to the Agreement under Article VI and Annex 13. The IJC's interest in land-use issues dates back to the seminal mid-1970s study of the Pollution from Land Use Activities Reference Group (PLUARG), which linked land-use practices to water-quality degradation. Since the Agreement's 1987 revision, urban land-use development has been a focus of efforts, and was addressed by the IJC in its 10th and 12th biennial reports.

During the 2003-2005 priority cycle, the Work Group on Parties Implementation undertook the following:

- A commentary on post-PLUARG progress on urban land-use issues;
- A review of the extensive literature regarding the types and effectiveness of stormwater best management practices;
- A computer simulation of an Ontario watershed, evaluating water-quality conditions in 1971 and in 2004 and, using the

2004 population, assessing several different combinations of urban form and stormwater management practices;

- An assessment of some of the recently revised State of the Lakes Ecosystem Conference suite of land-use indicators; and
- Parallel U.S. and Canadian studies of regulatory and institutional frameworks for urban land-use management.

However, implementation of PLUARG's advice was modest. The success of programs to reformulate laundry detergents and to reduce loadings of phosphorus from municipal wastewater treatment plants muted the focus on abating pollution from land-use activities and progress to mitigate contaminant loadings from non-point sources. Challenges such as managing nonpoint sources, the growth of confined-animal-feeding operations and controlling their considerable waste output, continued use of old pesticides, and urban sources of new pollutants, such as pharmaceuticals and personal care products, remain and are expected to intensify with the region's changing climate.

Urban areas discharge water to streams, rivers, wetlands, and lakes by three main flow routes: stormwater channels (storm sewers); outfall discharge from municipal wastewater treatment plants; and overflows from the collection system conveying water to municipal wastewater plants (combined sewer overflows). These are intimately interlinked and must therefore be managed in an integrated fashion. All three contain pollutants that can damage human health and the natural environment.

Stormwater runoff from industrial and commercial development can carry ten times the amount of phosphorus, five to eight times the amount of nitrogen, four times the amount of suspended solids, and 60 times the bacterial load compared to runoff from forested land. Vehicular traffic contributes additional pollutants to stormwater, including leaked fluids, byproducts of combustion, and high concentrations of zinc and copper from brake and tire wear. Roofs can also be sources of stormwater pollution.

The most obvious approach to treatment of urban stormwater is to convey it to an existing wastewater treatment plant. However, because of the high flow rates and the large volume of runoff that can occur during a storm event, it is very uncommon for a wastewater treatment plant to have the hydraulic and treatment capacity to process the large quantity of stormwater that flows off pavement and roofs. In Canada and the U.S., the most common form of stormwater treatment is diversion to a constructed pond or wetland in which stormwater can be detained and suspended sediment deposited.

Stormwater ponds and wetlands do not provide a consistent level of treatment. Although removal efficiencies of up to 80 percent of suspended solids (lower for other pollutants) are possible with ponds, actual treatment efficiency is often far lower. Concerns about low treatment efficiency, sediment toxicity, and poor removal of bacteria and viruses have prompted the investigation of alternative approaches that focus on reducing stormwater runoff by retention and infiltration of stormwater on site. Many of these aim to restore infiltration patterns and streamflow levels to predevelopment conditions by creating increased opportunities for percolation of rainwater into soils.

In 2004, the work group commissioned a computer-simulation study in cooperation with the Ontario Ministry of the Environment to evaluate the impacts of alternative urban forms and stormwater management options within a small watershed in Kitchener, Ontario. The results of the simulations, combined with analysis of historical records, demonstrate that urbanization has radically changed the quantity and quality of water leaving the watershed. These findings confirm those of many other studies: because cities have a high proportion of roofed and paved surfaces, less rainwater infiltrates the land surface, and consequently more runs off into surface receiving waters.

Urban form has diverse implications for the environment, including the type and quantity of pollutants generated, where those pollutants are discharged in the watershed, and what treatment measures are feasible. Urban form also has implications for transportation, the area and cost of land required (and therefore on land-use types such as agriculture that are displaced by urbanization), and the capital and operating costs to maintain that development.

The findings indicate that, where site conditions permit, compact urban form coupled with low-impact development stormwater control measures appear to be the preferred approach for managing urban stormwater in the Great Lakes basin. In areas not suitable for low-impact development measures, infiltration-based, wet-pond systems are a reasonable choice. The simulations also clearly demonstrated that actions in the headwater areas of a watershed are more effective than those in central watershed areas.

6.3.2 Waterborne Microbial Pathogens in the Great Lakes (Full report in Chapter Five)

Although diseases such as typhoid and cholera are no longer major problems in the Great Lakes basin, waterborne microbial pathogens still warrant attention. Outbreaks and deaths in Milwaukee, Wisconsin in 1993 and Walkerton, Ontario in 2000 illustrate that waterborne microbial pathogens pose a threat to human health. Most pathogens are transmitted by the fecal-to-oral route in which people are exposed when they ingest or come into contact with water contaminated with human or animal feces. Although attention and management efforts have focused on treating water and wastewater to prevent microbial contamination, human activities and advancements in technology continue to contribute directly and indirectly to contamination of surface and groundwater. For example, irrigation increases agricultural production, but the water returned to aquatic systems after agricultural use is often contaminated with nutrients and pathogens. Contaminated water used to irrigate crops can contribute to human illness following ingestion of raw unwashed foodstuffs such as lettuce and other vegetables. In order to manage microbial contamination, pathogens must be monitored in the environment and their fate and transport understood.

In the U.S., the number of disease outbreaks due to waterborne pathogens has increased since the late 1990s. The Centers for Disease Control and Prevention estimates that waterborne pathogens cause 300,000 infections per year. The largest outbreak in U.S. history occurred in the Great Lakes region (Milwaukee in 1993), where 400,000 people became ill and 100 died due to contamination of the drinking water supply. Outbreaks have also occurred in Canada, most notably at Walkerton in 2000, where seven people died from drinking-water contamination.

Microbial pathogens also pose a risk for contact recreation. In 1996, U.S. Great Lakes beaches were closed 3,700 times due to the presence of pathogens or indicator organisms. Globally, the cost of human disease caused by sewage pollution of coastal waters is estimated at four million lost "man-years" annually, which is roughly equivalent to an annual economic loss of approximately $16 billion (U.S). For one Lake Michigan beach, net economic losses due to beach closures were estimated to range from about $1,200 up to $37,000 per day.

Greater attention has been given to microbial pathogens because of an increase in the size of sensitive populations, global transportation networks that can spread pathogens worldwide, antibiotic resistance, and zoonotic transmission. New findings suggest that pathogens may be linked to diseases where their influence has never been suspected, such as hardening of the arteries. In addition, chemical and microbial contamination may interact to exacerbate effects.

In aquatic systems, pathogenic bacteria are a small component of a diverse microbial community. Pathogens are introduced to water systems by a variety of sources, although most are related to transporting human or animal waste into surface or groundwater. The most obvious route is the direct discharge of untreated sewage into waterways. Nonpoint sources also contribute to contamination, carrying pathogens from wildlife, livestock, or humans to water bodies via agricultural or urban runoff.

Agricultural runoff is a long-recognized source of pollutants to waterways; however, much of the attention has been on nutrient loads into aquatic systems. Agricultural runoff can also have a high microbial load, including bacteria and parasites.

Technological advancements of the last century put clean water into nearly all homes and built a sense of confidence in the water. As water travels from the drinking water treatment plant to the tap, the residual disinfectant levels may be depleted. Biofilms, which grow within the distribution system, include various opportunistic bacteria that may cause disease in susceptible individuals.

Given the threat to aquatic ecosystems and human health, information on the presence, distribution, fate, and transport of pathogens is critical for their management. Monitoring is essential for gaining this information. The IJC conducted a ground-breaking bacteriological study in 1913-1914. That effort, although lost to science for some time, was more comprehensive than current efforts. Indicators are commonly used to monitor for microbial pathogens rather than the pathogens themselves, because they are easier and less costly to sample and in many cases standard methods have been developed. Coliforms are the most common type of indicator. Many communities use fecal coliforms, or *E. coli*, as an indicator of human-fecal contamination.

A new management tool, the Hazard Analysis and Critical Control Point (HACCP) system, is widely used in the management of food and water quality and safety. The purpose of creating a HACCP plan is to document the major sources of risk to the end point of concern, identify and implement the major means of controlling those risks in practice, monitor to provide early warning of the failure of those control processes, and have corrective actions ready that could be implemented when control processes fail. Once completed and implemented, the HACCP plan provides confidence that the major risks have been identified, that ongoing operational controls are in place to manage the risks to water quality, and to give early warning if water quality is likely to become impaired. The plan can be improved over time using adaptive management, as well as through expansion of its scope and the rigor of its implementation.

Research and management needs for the Great Lakes basin with regard to waterborne microbial pathogens comprise three major elements: (1) an improved understanding of the natural history and ecology of pathogens and indicators to better detect and manage risks to human health; (2) a comprehensive strategy to monitor waterborne microbial pathogens; and (3) a comprehensive management approach to address and minimize the risks from waterborne pathogens.

6.3.3 Chemical Exposure and Effects in the Great Lakes Today (Full report in Chapter Five)

In the 1960s and 1970s, observations of reproductive failures in lake trout, mink, and fish-eating birds, gross deformities in fish-eating birds, and tumours and other deformities in bottom-dwelling fish demonstrated that significant quantities of unidentified toxicants present in the Great Lakes were capable of affecting the health and well-being of animals that eat fish, drink, and swim in Great Lakes waters.

Health Canada and the U.S. Agency for Toxic Substances and Disease Registry (ATSDR) initiated Great Lakes health-effects programs in the late 1980s that provided funding for investigations of human exposure and to establish human cohorts for cross-sectional and prospective epidemiological studies. Numerous epidemiological studies have documented effects on human reproduction and development, metabolism, and endocrine and immune function associated with Lake Ontario, Lake Michigan, and the St. Lawrence River. Adverse health effects are evident even in those individuals who consume relatively small amounts of certain Great Lakes fish.

The concentrations of PCBs and total DDT and its metabolites in fish and wildlife tissues showed almost no decline between 1990 and 2000. The concentration of PCBs in Great Lakes fish today remains many times above the U.S. Environmental Protection Agency's (EPA) acceptable level. Human embryos, fetuses, infants, and children continue to be the most susceptible populations. Gestational exposure to contaminants continues to be linked with functional impairment in children.

Concentrations of most persistent and bioaccumulative "legacy" contaminants have decreased substantially in the last 30 years due to source regulation. Mercury levels, primarily due to emissions from coal-fired power plants, have either remained constant or increased. Methylmercury (MeHg) is the leading cause of sport-fish consumption advisories in the U.S. and Canada. The U.S. National Research Council (NRC) has concluded that "the population at highest risk is the children of women who consumed large amounts of fish and seafood during pregnancy. The risks to that population are 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."

U.S. EPA has developed a methodology for deriving a reference dose (RfD) for acceptable chronic exposures to MeHg. The RfD of 0.1 microgram (ug) MeHg per kilogram of body weight (kg-bw) per day is a maternal dose based on developmental effects of mercury assessed in children who have been exposed *in utero* to mercury in the maternal diet. Using data from three epidemiological studies conducted in New Zealand, the Faroe Islands, and Seychelles Islands, the NRC determined that a fetal-cord blood of 58 ug/L was associated with twice the probability of adverse neurological effects in children. There is no evidence to date that a threshold blood-mercury concentration exists where effects on cognition are not seen. The NRC concluded that the likelihood of neurobehavioral deficits increased as cord-blood concentrations increased from five to 58 ug/L. The geometric-mean blood-mercury concentration for a sample of Asian-Canadian subsistence fishers in five Great Lakes Areas of Concern (AOCs) is 7.9 ug/L.

Concentrations of most persistent and bioaccumulative "legacy" contaminants have decreased substantially in the last 30 years due to source regulation. Mercury levels, primarily due to emissions from coal-fired power plants, have either remained constant or increased.

Evidence also suggests an association between rates of MeHg exposure from fish consumption with heart disease, particularly myocardial infarction. The causal mechanism may be an antagonistic interaction between MeHg and fatty acids, the latter known to provide health protection from heart disease. Other current research suggests that mercury is an immunotoxin, causing autoimmunity and autoimmune myocarditis. The immunotoxic effects occur at significantly lower doses than other impacts. These findings suggest that future fish-consumption advisories in the Great Lakes region, which are largely issued to protect women of child-bearing age and children, may need to be extended to other population segments.

It is well known that the combined effects of a mixture of dioxin-like compounds are additive when adjusted for potency. ATSDR is developing interaction profiles for some of the most common contaminants of concern in AOCs and contaminated sites using a weight-of-evidence approach. They recommend that mixtures be evaluated using a component-based approach that assumes additive joint toxic action.

Adequate long-term monitoring documents trends in the concentration of contaminants in the Great Lakes. However, there is no formal program in either country for gathering long-term evidence to determine trends in *effects* of contaminants on organisms. Well-planned monitoring anticipates surprises that arise out of ignorance, is essential to identify areas of uncertainty, and is fundamental to framing cost-effective and appropriate research questions.

Monitoring the vast array of chemicals in the environment, often in low concentrations, is a daunting challenge. It is possible to measure those chemicals for which there is a specific and sensitive analytical method and analytical standard. Using new sophisticated instrumentation and improved sample preparation protocols, chemists can identify an increasing suite of "new" chemicals or groups of chemicals whose concentrations are increasing in water and tissue.

The groups or classes of chemicals identified to be "emerging" contaminants of concern in the Great Lakes are:

- Brominated fire retardants (polybrominated diphenyl ethers and tetrabromo bisphenol-A);
- Perfluorinated compounds;
- Phthalates (a large class of plastic additives);
- Pharmaceuticals and chemicals found in personal care and household products;

- Estrogenic and hormonally active compounds (birth-control agents, natural estrogens, alkylphenol ethoxylates, bisphenol-A, Trenbolone); and
- Some currently used pesticides (Atrazine).

A number of strategies have been identified to address concerns related to new and emerging contaminants including:

- Working with industry to develop and implement cost-effective strategies for reducing ongoing releases to the environment from consumer products entering waste streams;
- Systematically monitoring concentrations in human blood and breast milk, sport fish, and fish-eating birds;
- Supporting research on the health effects of these chemicals in fish, fish-eating wildlife, and humans at environmentally relevant concentrations, singly and in mixtures;
- Formalizing and adequately funding programs for monitoring health effects in humans, fish, and wildlife;
- Providing appropriate funding to investigate the effects of pharmacologically and hormonally active chemicals in fish and fish-eating wildlife at environmentally relevant concentrations;
- Developing cost-effective strategies for collecting and destroying unused or expired medications, and for reducing and treating waste streams from hospitals;
- Introducing labeling programs for pharmaceuticals and personal-care products that enable consumers to make environmentally friendly choices concerning use and disposal; and
- Assessing the impact of contaminants in biosolid and liquid-manure applications to agricultural lands in terms of exposure and effects on terrestrial wildlife.

Fish-consumption advisories are a limited and temporary solution for public-health protection. Advisories externalize the economic costs to individuals and society by permitting the exposure of fish consumers to toxic chemicals. Subsistence fishers often depend on nearshore species (other than sport fish) that may be taken from more highly contaminated sites, including AOCs.

Great Lakes sport-fish consumption advisories provide excellent advice but have limited effectiveness. Women and minorities, two groups that advisories were designed to protect, are not adequately informed about the dangers of eating contaminated fish. One-size-fits-all advisories are not as effective as originally intended. The most vulnerable populations of fishers and consumers must be identified and specifically targeted with advisories that address ethno-cultural, nutritional, and economic concerns. Fish consumers could make appropriate choices if provided with comparative-risk information such as size, species, fishing location, or food type.

To eliminate or greatly reduce the number of fish-consumption advisories and the health effects in wildlife and humans in the Great Lakes basin, removal or capping of PCB-contaminated sediment is required. This is technically challenging and expensive. The effort to remove 90 percent of the PCBs from just the Fox River in Wisconsin will take at least five years and cost at least $500 million.

Mercury emissions also must be reduced by more than 90 percent from present levels to reduce or eliminate the many hundreds of fish-consumption advisories for small inland lakes in the Great Lakes basin. Alternative or improved remedial strategies need to be developed. To better justify the costs of remediation, efforts must be made to quantify the costs of the *status quo* to the health of wildlife and human populations at risk, and the costs associated with lost economic activity.

What evidence of human-health effects will be sufficient to create the political will necessary to clean up these areas that continue to contribute to system contamination? Research already shows that human-health effects associated with contaminants in fish include a range of serious health consequences involving neurodevelopmental, reproductive, carcinogenic, respiratory, behavioural, and circulatory problems.

Making wise, anticipatory decisions is not easy, especially when environmental or health impacts may be far into the future and the real or perceived costs of averting them are large and immediate. Protecting human health often requires acting before there is strong proof of harm, particularly if the harm may be delayed and irreversible. This approach to scientific evidence and policy making is part of the precautionary principle. A precautionary approach to chemical management incorporates four principles:

- Zero discharge;
- Reverse onus (including Responsible Care and Product Stewardship);
- Emphasis on classes of compounds; and
- Clean production.

The effort to remove 90 percent of the PCBs from just the Fox River in Wisconsin will take at least five years and cost at least $500 million.

6.3.4 Science and the Great Lakes Water Quality Agreement (Full report in Chapter One)

The SAB held a workshop in February 2004 to review the Agreement from a scientific perspective. The fundamental question considered was whether the stated purpose of the Agreement is necessary and sufficient to meet present and future challenges.

The workshop also focused on other themes related to the following questions:

- What is the present state of the science associated with the Agreement? Is the scientific knowledge implicit in the Agreement necessary and sufficient to achieve the Agreement's purpose?
- What new or additional scientific information is required?
- What new elements might be considered and what is the state of the science to support them?
- Can the existing Agreement accommodate present and future issues, including but not limited to alien invasive species, habitat, land use, climate change, biodiversity, pathogens, new chemicals, and long-range transport of atmospheric pollutants?
- Do current institutional arrangements under the Agreement help or hinder the application of science?
- Are current Great Lakes research institutions organized to deliver science in the 21st century?

Workshop participants advised the SAB that the following scientific principles be reflected in a revised Agreement:

Managing the Great Lakes needs to be broader than water quality. Present scientific knowledge is sufficient for a broad integrated understanding of water-quality problems involving the major ecological functions and the components of the watershed, the airshed, and groundwater. However, scientific knowledge is not adequate at present to manage the basin as an ecosystem.

A new Agreement must encompass numeric as well as process approaches in order to benefit from the latest scientific knowledge and information. Two complementary scientific approaches are currently being used: numerical, based on objectives; and process oriented, based on the most current understanding of the dynamic performance of the system. There are merits to the continued inclusion of both.

The interrelationship of water quality, ecosystem health, and water quantity is well established scientifically and should be recognized as such in a new Agreement. Examples of the interrelationship include tributary flow, groundwater discharge/recharge, and wetland dynamics in which the quality of the ecosystem is highly dependent on the amount of available water.

A binational scientific infrastructure to provide surveillance and monitoring information that supports policy and management must underpin any Agreement, and should be institutionalized as an essential component to linking science and policy.

The Agreement must be consistent and integrated with numerous other transboundary instruments. Some of its challenges are continental, *e.g.*, addressed under the North American Free Trade Agreement by the Commission for Environmental Cooperation, and global, *e.g.*, addressed by the International Maritime Organization through the International Convention for the Control and Management of Ship's Ballast Water and Sediments. To ensure that Great Lakes policies are coherent and effective, the Agreement would benefit from establishing scientific linkages among other instruments developed for the control of persistent toxic substances including the United Nations Economic Commission for Europe Convention on Long Range Transboundary Air Pollution and the United Nations Environment Programme – Persistent Organic Pollutants Treaty.

In addition to scientific principles, workshop participants also advised the SAB on broad aspects of the Agreement that need improvement, as well as specific recommendations by Article and Annex (see details in Chapter One).

While not discussed specifically during the workshop, a further opportunity to enhance scientific knowledge and understanding of Great Lakes ecosystems was identified by the SAB during the preparation of this report. The term "traditional ecological knowledge" refers to the important historic and anthropological understanding that aboriginal people possess based on their collective experience of living in the Great Lakes basin over thousands of years. Their knowledge offers a unique perspective to understand recent changes that have occurred to the basin ecosystem since European settlement, and this perspective is valuable to establishing goals to achieve restoration. The SAB urges the Parties to build on the capacity of Western scientific approaches through the incorporation of traditional ecological knowledge under a revised Agreement. The SAB notes that traditional ecological knowledge has particular relevance to restoration activities and ecosystem management goals in relation to sustainability.

6.3.5 Strengthening a Science-Based Approach to Great Lakes Water Management through Institutional Arrangements and Governance (Full report in Chapter One)

The relevance of institutional arrangements and governance to binational water management that sustains a science-based approach has been the hallmark of IJC involvement and progress under the Agreement since its adoption in 1972. The use of science is fundamental within the Great Lakes community as a basis for wise management decision-making and effective use of resources to progress towards Great Lakes restoration and protection. It was evident from the SAB's Expert Consultation on Emerging Issues that science continues to be essential in order to address future challenges and achieve progress in the 21st century on Great Lakes water management.

To determine how science can be strengthened through the enhancement of institutional arrangements and governance, the SAB's Work Group on Emerging Issues developed a work plan that extends into the 2005-2007 biennial cycle and encompasses a three-step process: (1) Work Group analysis and development of expert discussion papers to better understand existing arrangements, challenges, and opportunities; (2) assessment of the public input to the work group through the Institutional Arrangements and Governance Session at the IJC's 2005 Biennial Meeting held in Kingston, Ontario; and (3) hosting an expert consultation in the fall 2005 to develop findings and recommendations that address the scientific principles and overarching conclusions previously identified by the SAB. Since these activities were not concluded within the 2003-2005 biennial cycle, this is an interim report of the work planned and completed to date. Preliminary findings are presented; final recommendations will be provided after the conclusion of Step 3, the expert consultation.

In addition to determining those institutional arrangements and governance structures that facilitate a broad, science-based approach, the work group identified six specific issues as important to the challenge of developing new arrangements:

- Identification of key elements that contribute to the success of existing binational initiatives;
- Assessing the need for and role of a central coordinating body to implement Agreement commitments;
- Determining the role of local governments in the governance structure, and in particular the ten largest urban communities as defined by the IJC in its 12th Biennial Report;
- Determining whether special mechanisms are needed to promote public health as an explicit goal under the Agreement, particularly the avoidance of injury from transboundary polluting substances;
- Developing institutional arrangements to provide for shared management of surveillance and monitoring systems, *e.g.*, development of an integrated Great Lakes Observing System; and
- Identifying innovative or unique international approaches that have been adopted and proven successful in other transboundary commissions with similar goals of shared management of water resources.

Management approaches to large-scale international ecosystems or transboundary river systems vary widely, yet there are certain characteristics more successful management regimes share. Citing the Chesapeake Bay Program, the Helsinki Commission (Baltic Sea basin), the European Union Water Framework Directive, and the CALFED San Francisco Bay-Delta initiative, nine core characteristics common to the most successful programs were identified: (1) a high level of interagency, intergovernmental, and public-private information pooling; (2) integrated databases, common monitoring protocols, and joint ecosystem modeling; (3) a central coordinating body; (4) a set of functionally defined committees, subcommittees, or work groups; (5) central staff support; (6) a coordinated program of communications, public education, and outreach; (7) nested scales of governance; (8) specific goals and timetables at all levels; and (9) genuine integration across issue areas and mission-specific agency responsibilities.

6.4 Acknowledgements

The capacity of the Board to address priority issues and stay abreast of the latest scientific information is only possible through the dedication of its members, the involvement of the wider Great Lakes scientific community, and the participation of interested citizens and agency officials who cooperate and assist the Board whenever public meetings or input is sought on science-policy linkages. The Board wishes to express its gratitude and appreciation to the generosity of these exceptional friends and supporters: Robert E. Allen, Henry Anderson, Al Beeton, Michael Bloom, Lori Boughton, Elizabeth Brabec, John Brock, Mark Burrows, Murray Charlton, Jan Ciborowski, Sandra Cooke, Alan Crowe, Michael D'Andrea, Nicole Davidson, Anthony DeCaprio, Joseph De Pinto, Christopher DeRosa, Roger Eberhardt, Gary J. Foley, Jeff Foran, George Francis, John Gannon, Harold Garabedian, Mike Gardiner, Roger Gauthier, Ed Gazendam, Norm Grannemann, the Right Honourable Herb Gray, Gary Gulezian, Nick Heisler, Ron Hites, Keri Hornbuckle, Bradley Karkkainen, Shawn Keenan, Phil Keillor, Gail Krantzberg, Peter Kumble, Weng Liang, Hugh MacIsaac, Craig Mather, John F. McDonald, Ann McMillan, Chris Metcalfe, Jan A. Miller, John Mills, Lewis Molot, Sarah Moore, Derek Muir, Paul Muldoon, Elizabeth Murphy, James R. Nicholas, John Nevin, Peter Orris, Jim Patchett, Andrew Piggott, Leah Quiring, Susan Schantz, Lawrence Schell, Honorable Dennis L. Schornack, Dave Schwab, Adel Shalaby, Harvey Shear, Judy Sheeshka, Ted Schettler, Julie Schroeder, Harold Schroeter, Ellen Silbergeld, Paul Stewart, Rebecca Temmer, Kristina Thayer, Peter Thompson, Hugh Whitely, and Christine Zimmer.

6.5 Activities and Meetings of the Science Advisory Board for the 2003-2005 Biennial Cycle

131st Science Advisory Board Meeting
November 7, 2003
Great Lakes Regional Office

Special Presenters

- Scott Brown and Glen Fox: Environment Canada Preliminary SWAT Results from Selected AOCs Chosen on the Basis of Health Canada

132nd Science Advisory Board Meeting
February 4-6, 2004
Science and the Great Lakes Water Quality Agreement
The Michigan League
Ann Arbor, Michigan

Special Presenters

- Michael Donahue and Allan Jones: Workshop Purpose, Preamble, Articles I-IV and Annex 1
- Craig Mather and Jan Ciborowski: Nutrients and Non-Point Sources – Annexes 3 and 13
- David Carpenter and J. Milton Clark: Persistent Toxic Substances – Annex 12
- Joe De Pinto and Jan Miller: Dredging and Sediment – Annexes 7 and 14
- Gary Foley and Ann MacMillan: Airborne Toxic Substances – Annex 15
- Andrew Piggott and Jim Nicholas: Groundwater – Annex 16
- Bill Bowerman and Lori Boughton: RAPs and LaMPs – Annex 2
- Mike Gardiner and Leah Quiring: Coast Guard Annexes – Annexes 4-6 and 8-10
- Deborah Swackhamer: Surveillance, Monitoring, and Research – Annexes 11 and 17
- Glen Fox and Harvey Shear: Delivery of Science through the Agreement – Articles VII-XV

Work Group on Ecosystem Health
May 12, 2004
Consultation on Selected New Chemical Issues in the Great Lakes
Great Lakes Regional Office

Special Presenters

- Derek Muir: Concentrations of "New Chemicals" in Humans, Wildlife, and the Ecosystem of the Great Lakes
- Kristina Thayer: Perfluorinated Compounds
- John Brock: Phthalates
- Chris Metcalfe: Pharmaceuticals

133rd Science Advisory Board Meeting
May 13, 2004
Great Lakes Regional Office

Special Presenter

- Chris D. Metcalfe: Maintaining Chemical Integrity of the Waters of the Great Lakes Basin Ecosystem – Past Problems and Future Challenges

134th Science Advisory Board Meeting
September 30, 2004
Great Lakes Regional Office

Special Presenter

- Hugh MacIsaac: Invasive Species in the Great Lakes: Mechanisms of Introduction, Resource Management Implications, and Control Options

State of the Lakes Ecosystem Conference (SOLEC)
October 8, 2004, Toronto, Ontario
Work Group on Parties Implementation
Workshop on Urban Land Use Issues and Indicators

Special Presenter

- Marcia Valiante: Ontario Urban Land Use Programs and Policies

Great Lakes Commission/
U.S. Environmental Protection Agency
Post-PLUARG (Pollution from Land Use Activities Reference Group) Conference
November 8-10, 2004, Ann Arbor, Michigan
Work Group on Parties Implementation Presentation

Special Presenter

- John Braden: IJC/SAB Progress on Urban Land Use Issues in the Great Lakes Basin

135th Science Advisory Board Meeting
December 15-16, 2004
Great Lakes Regional Office

Special Presenters

- Bradley Karkkainen and George Francis: Governance Issues and Possibilities under a Renewed Great Lakes Water Quality Agreement
- John Braden: Economic Benefits of Sediment Remediation – A Review of the Evidence

Work Group on Ecosystem Health
Conference on Chemical Exposure and Effects in the Great Lakes Today
March 29-31, 2005
Metcalfe Federal Building, Chicago, Illinois

Special Presenters and Moderators

- Theo Colborn: Moderator
- David Carpenter: Keynote Address
- Henry Anderson: The Great Lakes Basin Exposure and Effects
- Paul Stewart: Oswego Cohort
- Susan Schantz: Human Health Effects of PCBs and Methylmercury: Using Data from Animal Models to Develop Testing Strategies for Exposed Children
- Donna Mergler: St. Lawrence River Studies
- Brian Gibson: Moderator
- Michael Bloom: New York Angler Cohort Study
- Lawrence Schell: Effects of Multitoxicant Exposure Among Akwesasne Youth
- Ellen Silbergeld: Immune Effects
- Glen Fox: Wildlife Effects
- Anthony DeCaprio: Serum PCB Congener Profiles: Clues to Exposure and Toxikinetics
- Elizabeth Murphy: Contaminant Concentration Trends in Great Lakes Fish Tissue
- Judy Sheeshka: Ontario Fish Intake and Consumption Advisories
- J. Milton Clark: Fish Consumption Advisories – U.S. EPA's Perspective
- Chris DeRosa: Risk Assessment and Mixtures
- Keri Hornbuckle: Perfluorooctane Sulfonate
- William Bowerman: Moderator
- Ron Hites: Brominated Flame Retardants
- Jeff Foran: Fox River Issues
- J. Milton Clark: Cleanup Activities
- Ted Schettler: Wrap-up: Where Do We Go From Here?

136th Science Advisory Board Meeting
April 7, 2005
Telephone Conference Call

137th Science Advisory Board Meeting
June 9, 2005
Public Meeting
Kingston, Ontario

6.6 Science Advisory Board and Work Group Membership 2003-2005

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Ann MacKenzie (to March 2005)
International Joint Commission
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Ann Arbor, Michigan

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International Joint Commission
Ottawa, Ontario

Key

1. Great Lakes Science Advisory Board
2. Work Group on Ecosystem Health
3. Work Group on Emerging Issues
4. Work Group on Parties Implementation

✢ ***Scott Brown (1950 – 2006)***

Scott Brown was born in 1950 and raised near Lake Winnipeg. He worked the land to finance his education and while doing so developed a strong land ethic. His approach to the Great Lakes mirrored the words of Aldo Leopold:

> *"A thing is right only when it tends to preserve the integrity, stability, and beauty of the biotic community – it is wrong when it tends otherwise."*

Scott joined the Freshwater Institute of the Department of Fisheries and Oceans in Winnipeg in 1970. He earned a Ph.D. in Zoology at the University of Manitoba in 1990. Scott moved to the National Water Research Institute of Environment Canada in Burlington in 1996 where he became a senior research scientist and Chief of the Priority Substances Effects Project. He was an international authority on vitamin deficiencies and endocrine disruption in fish and on related developmental problems such as Early Mortality Syndrome.

Scott was appointed to the Science Advisory Board in January 2002 and was also a member of the Workgroup on Ecosystem Health. In addition, Scott served on the Board of Technical Experts of the Great Lakes Fishery Commission.

Scott passed away suddenly in June 2006. We will miss his knowledge and ecological wisdom and his good sense of humour. We will remember his passion for the Great Lakes, his friendship, the sparkle in his eyes, and his devotion to family.

Chapter Seven

COUNCIL OF GREAT LAKES RESEARCH MANAGERS

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Chapter Seven

COUNCIL OF GREAT LAKES RESEARCH MANAGERS

7.1 Introduction

The Council of Great Lakes Research Managers advises the International Joint Commission (IJC) on matters related to Great Lakes research programs and needs. Created by the IJC more than 20 years ago, the Council enhances the ability of the IJC to provide effective leadership, guidance, support, and evaluation of Great Lakes research. In particular, the Council shows how research within the Great Lakes satisfies the requirements and intent of the Great Lakes Water Quality Agreement. The responsibilities of the Council include:

- Promoting effective communications, collaboration, and coordination among researchers and agencies in Canada and the U.S.;
- Encouraging researchers to share their findings with basin policymakers, resource managers, and the public through common reporting mechanisms;
- Stressing the policy implications of research findings;
- Compiling and summarizing current and planned research programs related to the Agreement, in particular those required by Annex 17 (Research and Development);
- Identifying and prioritizing research needs to encourage the U.S. and Canadian governments to fund studies directly relevant to the Agreement's purpose; and
- Reviewing the impact of research recommendations made by the Council, the Great Lakes Science Advisory Board (SAB), the Great Lakes Water Quality Board (WQB) and the IJC.

Council membership consists of individuals who manage federal, state, and provincial research programs in the U.S. and Canada, as well as representatives from academic institutions and private industry. Representatives of the Great Lakes Fishery Commission and the International Association for Great Lakes Research (IAGLR) also participate. All serve in their personal and professional capacity at the pleasure of the IJC, usually for terms of three years.

During the 2003-2005 priority cycle, the Council focused primarily on activities that directly relate to Annex 17 (Research and Development) and Annex 11 (Surveillance and Monitoring): the development of a strategy to coordinate Great Lakes research, and the formation of an integrated Great Lakes observing system. The Council also continued collaboration with the SAB and the WQB to identify new priorities and areas of the Agreement affected by advances in science and understanding of the Great Lakes ecosystem. The Council further developed the Great Lakes–St. Lawrence Research Inventory, promoted coordination of science vessel operations, and organized workshops at the State of the Lakes Ecosystem Conference (SOLEC) and the 2005 Great Lakes Conference and Biennial Meeting in Kingston, Ontario.

Two major workshops on the research coordination strategy and the future of open water observation technology resulted in excellent advice and guidance from Council members and participants to inform the Council's advice to the IJC. Proceedings from those workshops are provided in separate publications, with summaries below. However, much remains to be done to refine the vision, implement recommendations, and unify efforts on these two activities. The success of both initiatives will greatly improve our ability to effectively focus monitoring and research to address critical scientific questions, and thus better understand the Great Lakes environment. A fully integrated network of sensors to "take the pulse" of the Great Lakes will alert us to changing conditions, better inform management and policy decisions, and eventually enable scientists to forecast the impact of human activities, climate change, and emerging stressors on the ecosystem.

The Council acknowledges the efforts of all who lent their support during the past two years: U.S. Environmental Agency (EPA) support staff at the Great Lakes National Program Office, especially Pranas Pranckevicius; Amber Lahti and Angie Wagner from the Upper Lakes Environmental Research Network; the support staff of the Great Lakes Environmental Research Laboratory (GLERL) and the IJC Great Lakes Regional Office, in particular Laura Newlin, Giovanna Stasiuk, and Jill Mailloux for their technical support and efforts to coordinate workshop logistics; the Great Lakes Commission, in particular Roger Gauthier and Jon Dettling; Dr. Tom Johengen with the Alliance for Coastal Technologies; and Dr. Guy Meadows with the University of Michigan. These individuals, along with Council members who volunteered many hours to help to plan, lead, and

document the proceedings of workshop sessions, contributed to the success of Council activities and to the content of this report. Their assistance is greatly appreciated.

7.2 The Future of Open Water Observation Technology for Great Lakes Research

The Council, in partnership with the National Oceanic and Atmospheric Administration's (NOAA) GLERL, hosted a workshop in December 2004 entitled "The Future of Open Water Observation Technology for Great Lakes Research." More than 60 participants convened in Ann Arbor, Michigan to discuss the potential of recent developments in open water observation technology to impact how scientific research is conducted in and about the Great Lakes. Over four days, participants shared new ideas and developments, discussed challenges and opportunities, and brainstormed ideas regarding collective actions and future directions.

Leading experts on open water research from the Great Lakes and other regions presented the current state of monitoring technologies and the promise of several emerging technologies. Considerable attention was given to the relative costs and benefits of implementing each on a wider scale in the Great Lakes. Technologies included a wide variety of monitoring options, including moored buoy systems, autonomous vehicles, ship-based observations, and satellite/aerial imagery, among others. The presentations clearly described observations being conducted over the Great Lakes, research questions being addressed, additional existing options, and emerging opportunities to enhance over-water observation systems in the region.

In breakout groups, the participants considered the physical, biological, and chemical aspects of open-water observing technologies. Each group focused on identifying fundamental research questions, required observation data, gaps in monitoring systems, and the adequacy of technology to fill those gaps. New sensor technology to gather additional data was recommended and areas identified where such technology needs to be developed. In addition, participants brainstormed on the ability of enhanced open water monitoring to fulfill the needs of restoration goals identified by the Council of Great Lakes Governors.

The results of the breakout group discussions are presented below.

7.2.1 Physical Sciences

The physical sciences group identified seven key questions to be answered by a Great Lakes observing system:

1. How well are over-the-lake meteorological conditions measured and predicted by the current shore-based systems and National Data Buoy Center (NDBC) buoys?
2. What are the dominant physical processes responsible for lateral and vertical transport on various spatial and temporal scales? These scales include:
    - Seasonal overturn;
    - Episodic events (*e.g.*, eddies, passing storms);
    - Turbulence, internal waves; and
    - Effects of ice.
3. What are the impacts of changing ice cover on the thermal and hydrological budgets of the lakes? How will impacts change over time?
4. Are we seeing long-term changes in the thermal structure and circulation dynamics of the lakes?
5. What is the relationship of Great Lakes physical conditions to global climate dynamics (*e.g.*, El Niño/Southern Oscillation and the North Atlantic Oscillation)?
6. Are the sediment dynamics and budgets of the lakes changing? These include:
    - Lakewide sediment budgets;
    - Nearshore processes; and
    - River loadings.
7. How do nearshore sediment dynamics respond to meteorological conditions? What are the linkages to turbidity, light availability, and substrate composition?

The group also discussed physical data that need to be collected by a Great Lakes open water observing system to answer these questions. The major types of physical data are:

- Meteorological data;
    - Standard NDBC suite of sensors (also for waves);
    - Precipitation and evaporation at offshore moorings; and
    - Upward and downward radiation.
- Temperature loggers;
- Acoustic Doppler Current Profilers (ADCPs);
- Pressure;
- Light and turbidity; and
- Time-series sediment traps.

The standardization and comparability of physical parameter data needs to be improved. Also needed is a combination of spatially distributed and fixed-point data collection methods.

Relative to the physical science needs identified above, major gaps in the current open water observing infrastructure include:

- Insufficient or no wintertime observations because few if any measurements are taken when the lakes are iced over;
- Lack of long-term moorings for water column measurements taken synoptically in all the Great Lakes;
- Lack of autonomous underwater vehicles (AUVs)/gliders, and the monitoring benefits that these units provide;
- Very few ship observations except for occasional regional initiatives;
- Few or no drifters or autonomous profilers; and
- No CODAR (coastal radar) measurements are being taken.

The group further identified that a more thorough and scientific analysis of current and potential monitoring systems is needed. Through such an assessment, numerical models should be used to determine, for example, how many moorings and vehicles are needed in each lake to fulfill the identified needs.

For the most part, current technology–if adequately implemented–is sufficient to achieve the scientific goals identified by the group, although some technological advances are still needed, including:

- Evaporation and precipitation measurements on buoys to ground-truth remote sensing data;
- Higher frequency measurements of wind, relative humidity, and certain gases (*e.g.*, carbon dioxide) to calculate fluxes at the air-lake interface;
- Instrumentation that can measure suspended-sediment concentrations in the water column, such as by acoustic techniques;
- Improved capabilities of CODAR systems for fresh water, possibly involving use of higher power. Bi-static CODAR systems that include transmitters on buoys as well as on shore are another possibility;
- Operational hyper-spectral satellite and Synthetic Aperture Radar (SAR) measurements to measure ice cover, among other things;
- ADCP measurements on a fine scale at the benthic boundary layer; and
- Atmospheric deposition measurements taken over the lakes.

7.2.2 Chemical Sciences

The chemical sciences group described nine fundamental scientific needs related to lake chemistry to be addressed by an open water observing system:

1. Better understanding of the fluxes of chemicals across media, including air-water, sediment-water, and land-water. This is necessary to quantify chemical mass budgets for the lakes and applies to a wide range of persistent bioaccumulative and toxic chemicals, nutrients, microorganisms, carbon, and other chemicals. Quantifying these fluxes requires measurements at higher resolution.
2. Better understanding of nearshore-offshore coupling and the influence of physical processes.
3. Better understanding of pathways by which chemicals are taken up by biota. Identification is needed of the most important emerging chemicals on the basis of their in-lake effects. This also requires the ability to measure chemicals in multiple phases, providing full speciation of congeners or enantiomers.
4. Better determination of the role of atmospheric inputs of nutrients on the lakes' trophic state.
5. Improved evaluation of the temporal and spatial variation of atmospheric deposition of chemicals to the lakes.
6. Better understanding of the coupling of physical processes to chemical and biological processes. Quantification is needed of the spatial and temporal gradients in chemicals and how these are affected by physical processes.
7. Quantification of long-term trends in chemical concentrations in the lakes. The ability to elucidate long-term trends by measuring and understanding inter-annual variability is needed.
8. Measurements of the effects of short-term (potentially episodic) fluctuations in forcing functions (*e.g.*, loads, solar radiation inputs, heat transfer, circulation) on system response variables (*e.g.*, primary production, larval fish survival). Capability must be developed for these measurements to validate high-resolution forecasting models.
9. Determination of mass balances of nutrients and toxic chemicals as well as recovery trajectories and the long-term response of the system to historic loadings. Determining ultimate sources of chemicals to the lakes is needed, including proximate sources versus long-range transport, and urban sources versus rural/background.

The group next developed a conceptualized open water observing system to address these issues. The major characteristics of such an observing system include:

- An integrated system of buoys, towers, shore installations, AUVs and Remotely Operated Vehicles (ROVs), bottom-resting structures, sensor chains to capture vertical profiles, and sediment traps;

- Installations to capture three-dimensional gradients in water and air above water, including measurements at various heights and depths;
- A system that provides high temporal resolution, from continuous to daily scales;
- Systems laid along transects perpendicular to the shoreline (especially off major urban or tributary sources) that can capture signals of chemicals from these sources (both in air and water) and how they dissipate over distance from the source;
- Measurements of tributaries to complement open water measurements in assessing mass budgets;
- Sequential sediment traps to monitor sediment-water exchange; and
- Passive samplers for chemicals in air and water.

The major chemical parameters to be measured by the open water observing system include:

- Nutrients: nitrate by sensor; total phosphorus, phosphate, ammonium, and silicon by flow injection analyzers (FIAs);
- Dissolved oxygen by sensor;
- Fluorometric methods for chlorophyll and dissolved organic carbon;
- Carbon dioxide;
- Persistent bioaccumulative toxics, including hydrophobic organics, heavy metals, and pesticides (*e.g.*, atrazine) using discrete sampling and passive samplers in air and water;
- Particulate matter by continuous measurement (turbidity, transmissivity) and discrete sampling;
- Sediment traps sequenced to capture temporal variability;
- Light: Depth profiles through hyperspectral measurements to assess vertical light extinction;
- Three-dimensional wind profiles (sonic anemometer) with motion correction; and
- Relaxed eddy accumulation; however, this needs research and development.

A thorough understanding of food-web dynamics and well-functioning ecosystems is essential, as opposed to non-functioning systems due to invasive species or disease. Trophic signatures can determine if each system is gaining ground toward becoming self-sustaining.

Sensors are available for many of these parameters, but not for others. Therefore, sampling of water and other media for laboratory analysis will be required for the foreseeable future. Among the major technological advances needed to improve the capabilities for open water observing of chemical parameters are further developments of:

- Relaxed eddy accumulation;
- Fine-scale measurements without continuous sensors (*e.g.*, FIA);
- Biological sensors (*e.g.*, DNA probes, immunoassay techniques, gene expression arrays);
- Nutrient sensors for phosphorus or silicon;
- Automated, miniaturized measurement systems with reduced power demands and reduced servicing needs (*e.g.*, reduce fouling); and
- Increased sensitivity and speed of analytical technologies.

7.2.3 Biological Sciences

The biological sciences group discussed several major themes for the use of an open water observing system to answer questions concerning Great Lakes biological science. Major issues are the need for improved temporal and spatial scales, identification of the forcing functions in the system, and research into biocomplexity. An advanced open water observing system could help improve human understanding of fish life cycles, fish production, and relationships between habitat and water levels. Such a system also will connect information across spatial and temporal scales.

An identified gap in current Great Lakes open lake monitoring systems is monitoring of nearshore areas (*i.e.*, to 5-meter depth). These areas are sensitive and can be difficult to instrument. Remote sensing, aircraft imaging, or light detection and ranging may be possible solutions. Remotely controlled devices could potentially be used to take fine-scale water levels, vegetation, substrate conditions, and temperature.

Physical-chemical structure (forcing) should be related to biological community structure, such as through habitat-mediated effects. It was also noted that each of the Great Lakes represents different systems, and processes may differ in each. Physiology needs to be connected with ecology, for example by developing a better understanding about how fish and other aquatic organisms "see" or sense their environment.

A thorough understanding of food-web dynamics and well-functioning ecosystems is essential, as opposed to non-functioning systems due to invasive species or disease. Trophic signatures can determine if each system is gaining ground toward becoming self-sustaining. A broad array of indicators or characteristic signatures must be developed for each lake to determine lake health and ecosystem change. For example, an indicator could be based on zooplankton size frequency, and monitoring results could be compared to typical patterns to detect shifts toward larger or smaller populations. Additional key parameters include fish concentration and distribution at any time, fish movement around a lake, and size of broodstock.

An open lake observing system will be essential to detect episodic events and the conditions leading up to them. The system will also better characterize spatial heterogeneity and patchiness, and relationships of heterogeneity to forcing factors.

There is potential for using spectroscopy for classification of plants and phytoplankton (species, physiological state) based on spectral signatures. Flow cytometry is a potentially useful tool for characterizing phytoplankton.

Open water observing also has considerable potential for improving understanding and prediction of harmful algal blooms. For example, sensors can be deployed to measure species composition, toxicity, and environmental conditions to determine ecosystem function signals (*e.g.*, a shift to blue-green algae) and form predictive links to other forcing functions. Plankton counters would be particularly beneficial in this regard.

An open water observing system would also provide valuable information to determine interactions between the lakes. Intensive instrumentation in the connecting channels would provide necessary information on the boundary conditions, nearshore, river mouths, and nutrient loading/concentrations.

With the exception of satellite imagery, no biological data are being collected uniformly across all the lakes at the same time, or using the same technique. Although biological data are clearly under sampled, the appropriate sampling rate has not been determined. Sampling needs to be more consistent and increased over broader time scales to generate hypotheses. Wherever possible, the ability to view data in real time presents a large advantage and should be the preferred option. Obtaining sensor data in real time allows the data to guide more intense (*i.e.*, fine-scale, episodic) research.

Current sensor technology is capable of achieving the majority of the needs identified; however, attended operations are required. Unattended, reliable, and low-maintenance tools are needed. There are a host of new technologies in various stages of development, but their operational feasibility is untested.

Measurements of survivorship and recruitment of fish larvae are also needed to predict year-class strength, which includes determination of the variables needed to make this prediction. The observing system will provide valuable information for studying trophic transfer and parasite dynamics.

Additional biological questions that an observing system could help answer include:

- Why are perch populations thriving in one place and not in another?
- Why are salmon moving from Lake Huron to Lake Michigan?
- What are the essential driving forces for ecosystem change (*e.g.*, climate change, land use, invasive species)?
- What is the primary production in each lake?
- What is the carrying capacity of each lake?

A preliminary list was compiled of technologies and characteristics that should be incorporated into a Great Lakes open water observing system to obtain adequate biological data. Identified components include:

- Conductivity-temperature-depth recorder, fluorometer, light, transmissometer, multi-frequency acoustics, *in situ* spectrophotometers;
- Sensors in the offshore, nearshore, tributaries, and connecting channels;
- Deployment patterns that vary by lake and are issue driven (*e.g.*, anoxia). For example, monitoring of sediment interface exchange is more important in Lake Erie than in Lake Superior;
- Benthic habitat mapping; and
- Monitoring of benthic macroinvertebrates, such as through imaging or acoustics.

7.2.4 How a Great Lakes Observing System will Help to Address Restoration Priorities

Momentum is increasing across the Great Lakes region to establish a basinwide restoration initiative. Draft legislation in Congress proposed investing large amounts of money in a series of well coordinated efforts to overcome many of the basin's environmental challenges. To guide the establishment of such an initiative, the Council of Great Lakes Governors established a Restoration Priorities Task Force, which issued nine basinwide restoration priorities in October 2003. On the workshop's third day, a group discussion was held to identify the role of an open water observing system in implementing a large-scale restoration plan, and, in particular, how each of the Council of Great Lakes Governors' priorities might be affected. Each priority will require monitoring of baseline conditions and progress toward identified goals. Expansive and consistent measurements in the open water will be essential in this goal-setting and tracking process. One of the Council of Great Lakes Governors' nine priorities (to standardize and enhance the methods by which information is collected, recorded, and shared within the region) is central to the observing system itself and was not discussed explicitly. The other eight priorities are:

1. Ensure the sustainable use of water resources while confirming that the states retain authority over water use and diversions of Great Lakes waters;
2. Promote programs to protect human health against adverse effects of pollution in the Great Lakes ecosystem;

3. Control pollution from diffuse sources into water, land, and air;
4. Continue to reduce the introduction of persistent bioaccumulative toxics into the Great Lakes ecosystem;
5. Stop the introduction and spread of non-native aquatic invasive species;
6. Enhance fish and wildlife by restoring and protecting coastal wetlands, fish, and wildlife habitats;
7. Restore to environmental health the Areas of Concern (AOCs) identified by the IJC as needing remediation; and
8. Adopt sustainable-use practices that protect environmental resources and may enhance the recreational and commercial value of the Great Lakes.

The role of an open water observing system in implementing actions was identified to address each priority, along with specific measurements to be taken or characteristics of the observing system that will be required.

Water Diversions

The Great Lakes Charter Annex 2001 states that water use and diversions should have no detrimental impact on the ecology or waters of the Great Lakes. An accurate forecast of the ecological consequences of a proposed water diversion will be required in order to implement this policy. An observing system could identify ecological impacts of water level changes in the basin and significantly improve estimates and understanding of the water budget within the Great Lakes. Cumulative withdrawals, inflows, and outflows could be more thoroughly monitored and linked to water levels. Ecological impacts from significant changes in water levels due to changes in natural cycles or as a result of existing withdrawals could be monitored. This information would enable scientists to more accurately model the system, forecast the impact of a proposed water use or diversion and provide a valuable tool to inform the decision-making process.

A recent study of biology-hydrology interactions in the Great Lakes examined the impacts of water withdrawals on the open lakes. The largest amount of uncertainty in estimating impacts is in the nearshore and head waters. Emphasis should be placed on changes in the nearshore zone, although implications can also be extended to offshore zones, such as deep-water species that use nearshore areas for breeding.

A thorough system of open water observations could improve currently poor understanding of the factors used in estimating evaporation. Similarly, currently inadequate estimates of precipitation over the lakes could be greatly improved by enhanced over-water monitoring. Flow measurements can provide a more accurate baseline measure to gauge cumulative effects. Additional questions include:

- What is the manifestation of water loss on offshore ecology?
- What is the impact of global climate change on water levels?
- Are there strategic times or places where impacts of withdrawals or diversions would be minimized?

Human Health

An advanced observing system would have significant implications for protection of the region's human health. Monitoring drinking water sources for accidental and purposeful contamination would be valuable. Monitoring and prediction of bacterial contamination at beaches is essential to provide accurate beach closures and warnings. Bacterial monitoring, offshore circulation, and meteorology are essential for this purpose. In addition, improved identification of various *E. coli* strains and other coliform bacteria will lead to better predictions of human-health impacts from beach bathing.

A better understanding of the air-water interface and atmospheric transport and deposition processes will provide more accurate contaminant loading estimates. Tracking harmful algal blooms will be possible with open water observations, and models might be developed to better predict when these events might occur. Open water observations are also highly important for maritime safety, emergency response, and search and rescue operations, all of which relate to human health.

Developing a good open water observing infrastructure will provide a platform for development of the next generation of sensor technology. Additional technological developments that may emerge in coming years include the ability to identify and trace biological indicators of water quality. Developing a better understanding of open water ecosystems will allow detection of subtle changes in critical indicators caused by pollutants, pathogens, and/or introduced toxins. Maintaining a healthy fishery is vital to enhancing human health in the region. Knowledge of fish location and migration can help improve prediction of fish contamination. This may be particularly important if proposals for aquaculture in the lakes increase.

Nonpoint Source Pollution

An open-water observing system would increase measurements of material fluxes into and out of the lakes. This information could better identify and pinpoint sources of runoff pollution, as well as evaluate the effectiveness of control strategies. Identification of sources and source regions is an essential first step in pollution-prevention programs. Monitoring information combined with improved tributary loadings would provide a better understanding of tributary and atmospheric loadings to the lakes. Clearly, in addition to open water systems, thorough tributary monitoring is required. Also, high-quality open water monitoring data could be used to integrate and evaluate the impacts of large-scale land use decisions on water quality, and to predict long-term impacts and recoveries.

Persistent Bioaccumulative Toxic Substances (PBTs)

Consistent open water and over-water sampling for toxic substances would provide a baseline to assess progress in controlling these substances. Measurements of the benthic flux of toxics (*i.e.*, resuspension) by biological and nonbiological processes would provide essential information to understand the cycling of toxic substances. Improved understanding of trophic structures will greatly improve bioaccumulation models.

Recently developed technologies have great potential to improve PBT monitoring in the lakes and in the air above them. The Sarnia-Lambton Environmental Association has implemented a spill-detection system on the St. Clair River. Similar systems in numerous other parts of the Great Lakes at high risk of chemical spills would be valuable. Passive samplers have also been used to monitor PBTs in ambient air. These have the potential to be adapted to buoys for over-water monitoring.

Habitat

To effectively protect, preserve, and restore Great Lakes basin habitat, baseline information must be categorized and a scale developed to measure changes and evaluate the effectiveness of control measures. Remote observatories should be designed to assess habitats under restoration. Open water observations and satellite/airborne imagery could map habitat and determine the response of wetlands to water-level changes. Such systems could also measure the impact of restoration activities, such as the effects of new sources of clean water entering the system and benefits to the lake as a whole. Acoustic monitoring could track fish populations. Improved understanding of habitat and ecosystem processes could have far-reaching benefits, such as understanding and predicting situations that lead to botulism outbreaks and harmful algal blooms.

Restoring Areas of Concern

An open water observing system has several important implications for the AOCs, all of which are in coastal or tributary areas. Predicting and measuring the impacts of restoration projects on open lake water quality is important. Measuring routine sediment and dredging disturbance will enhance understanding of contaminant cycling. AOC restoration is poorly monitored after cleanup projects are concluded. Components of an open water observing system could partially make up for this shortfall.

Aquatic Invasive Species

Tracking the spread and quantifying the effects of aquatic invasive species can be greatly improved by open water observing systems. A system of open water observations would be an important management tool for assessing conditions, likelihood of invasion, and survival of invasive species in specific sites. In addition, the system would provide a baseline and long-term understanding of the system. Routine monitoring is essential for early detection based on subtle ecosystem changes. Improved understanding of ecosystem structures might also reveal areas that are particularly sensitive to introduction and spread of invasive species. In addition to monitoring in the Great Lakes, better global monitoring for invasive species is important.

Sustainable Use / Recreational and Commercial Value of the Great Lakes

Assessing the long-term sustainability of the Great Lakes ecosystem requires the monitoring data being discussed for the open water observing system. The system will provide baseline data and data for measuring success of restoration action, or further deteriorations. The system would provide long-term trends in biological inventories and a large-scale, integrated, and accurate assessment of the impacts of various Great Lakes uses. Modeling and analysis tools to support management decisions can also be implemented. The Great Lakes Observing System (GLOS) is fundamental to creating the capacity to forecast potential changes in the system resulting from use (and/or misuse) and changes-to-use patterns. GLOS will enable advanced forecasting capability. Data distribution to the public in a productive and engaging way will help decision makers and the public understand the impacts of actions. The system also must provide improved nearshore observations and forecasts. There could be a substantial spin-off of new products with commercial value.

The Governors' nine priorities are focused on ecological restoration and, although they refer to socio-economic aspects of the lakes, several Great Lakes issues may be obscured or neglected by focusing only on this set of priorities. Additional frameworks that may benefit from discussion include the seven societal goals recognized by the Global Earth Observation System of Systems initiative and the Commission on Ocean

Policy's recent report. Navigation is one area that could be critically improved by open water observing, but is not directly reflected in the priorities discussion. Commercial shipping interests would benefit from near-term forecasts of water levels and meteorological data. Additionally, homeland security issues should be addressed. Sensors could be incorporated to detect bioterrorism and track cleanup efforts, providing an incredibly useful tool for emergency responders.

7.2.5 Recommendations

The Council of Great Lakes Research Managers recommends to the International Joint Commission that:

- **The Parties insert language into a revised Agreement that provides for coordination of United States and Canadian participation in the Great Lakes portion of the Global Earth Observation System of Systems.**
- **The Commission actively support and participate in the implementation of the Great Lakes portion of the Global Earth Observation System of Systems and promote widespread binational participation from all agencies and organizations.**

7.3 Great Lakes – St. Lawrence Research Inventory

The Great Lakes–St. Lawrence Research Inventory (http://ri.ijc.org) is an ongoing Council responsibility. The Research Inventory is a web-accessible database of research projects conducted in the Great Lakes region that contains a brief descriptive summary of each project. The data can be sorted in a wide variety of ways to identify studies of interest, and contact information is provided to facilitate networking among Great Lakes researchers. Various summary charts may be produced from the site to characterize the distribution of projects and areas of focus. Registered users may enter data about their research project. Each project is screened and validated by the Council secretary, and related to relevant sections of the Agreement. This enables the program to sort the data by Agreement sections. These parameters, together with summary data about the number of projects, geographic distribution, and funding, provide Research Inventory users with a way to evaluate areas of emphasis, assess government support of the Agreement, identify possible gaps and target resources in an effective manner.

7.3.1 Recent Enhancements to the Research Inventory

The Council continues to improve the user interface and utility of the Research Inventory web site and to promote participation. The site houses summaries of more than 740 current and past projects. During the past two years the program was enhanced with new user-help features, access to individual project descriptions from summary charts, and administrative functions to maintain data integrity. In addition, program sub-routines were developed that enable the Council to modify and update inventory tables and to facilitate streamlined loading of projects from agency/university data bases. These tools provide the flexibility to accommodate changing needs.

Keeping pace with the growing number of project databases, building awareness of the inventory, and encouraging participation are ongoing challenges. In October 2004 the Council teamed up with representatives from Environment Canada to organize and coordinate a workshop at SOLEC entitled "Monitoring Coordination and Information Management." Participants were briefed on Canadian and U.S. federal and provincial initiatives underway to inventory Great Lakes monitoring program archives and make data available on the Internet. These efforts support several different programs including the Canada-Ontario Agreement, Lakewide Management Plans, the Great Lakes Binational Toxics Strategy, and SOLEC. In 2004 the Parties' Binational Executive Committee launched the Great Lakes Monitoring Inventory on www.binational.net and adopted a basinwide rotational cycle for cooperative monitoring to address key information needs and to facilitate access and sharing of Great Lakes data.

The workshop reviewed the status and possible means to integrate these initiatives, which led to improved collaboration among agencies. The Council also exchanged Research Inventory data with the Lake Erie Millennium Network and agreed to exchange data with the Great Lakes Monitoring Inventory.

Other efforts underway include collecting and verifying the aquatic invasive species projects in the Inventory. The project will report on the temporal patterns of funding for work on aquatic invasive species in the Great Lakes basin over the past five years. A marketing plan has been created for the Research Inventory, and outreach efforts were conducted at the IAGLR conference in May 2005.

7.3.2 Recommendation

Since the Council's 2001-2003 Priorities Report, the number of projects in the Inventory has grown from approximately 570 to more than 740; however, the voluntary nature of the Inventory, the lack of incentives, and resource limitations continue to limit participation. Accordingly, the Council recommends to the International Joint Commission that:

- **The Parties encourage organizations that grant funds for Great Lakes research to routinely use the Great Lakes-St. Lawrence Research Inventory as a tool to evaluate research proposals, avoid duplication of efforts, and to help identify existing programs that could contribute expertise and effectively use research dollars.**

7.4 Science Vessel Coordination

7.4.1 Background

Science vessels are used throughout the Great Lakes and in the St. Lawrence Seaway for research, training, and outreach by public agencies, academic institutions, and private industry. They are a critical part of Canadian and U.S. research and monitoring programs targeted at protecting the quality of the Great Lakes ecosystem. Sixty-eight science vessels are active in the Great Lakes and St. Lawrence River. These vessels come in a wide variety of shapes and sizes, but average 60 feet in length.

The average vessel is more than 30 years old, much older than typical commercial fleets. The 40 different agencies, universities, other organizations, and the crews operating these ships should be praised for their ability to maintain such a long service-life.

Even with the best care, ships eventually must be replaced; however, only a few new or rebuilt ships have been launched in recent years. Maintaining existing ships typically places the biggest demands on research budgets; significant cost savings may be achieved through measures to share resources and more efficiently carry out shipboard operations.

To promote better coordination of efforts, annual science vessel coordination workshops have been held since 1997. These workshops have been organized by a steering committee comprised of members from the Great Lakes Commission, U.S. Geological Survey's Great Lakes Science Center, NOAA's GLERL, Ontario Ministry of Natural Resources, U.S. EPA's GLNPO, the Canada Department of Fisheries and Oceans, Buffalo State College Great Lakes Center, Grand Valley State University, the University of Wisconsin-Milwaukee's Great Lakes Water Institute, the Canadian Coast Guard, and the Council.

An action plan created in 1997 serves as a guide throughout the process. The workshops provide an excellent forum for the exchange of ideas and over the years have focused improvement efforts in three areas: advocacy, standards development, and marine personnel requirements. This has evolved into the Great Lakes Association of Science Ships (GLASS) and work groups have formed to address administrative needs, vessel utilization, standards development, and personnel issues. In addition, a science vessel web page has been established (www.CanAmGLASS.org), which hosts an interactive science vessel database containing comprehensive information on each science vessel in the Great Lakes.

7.4.2 Workshops

The Eighth and Ninth Annual Great Lakes Science Vessel Coordination Workshops were both held in Traverse City, Michigan, in partnership with the Great Lakes Maritime Academy (GLMA). Workshop organizers acted on recommendations from previous workshops by taking advantage of the excellent training facilities available at the academy. Participants were offered a choice of marine engineering training sessions at GLMA during the eighth annual workshop, which were so popular they were repeated in 2005. The workshops also provided an opportunity for participants to discuss recent successes, such as the Teacher Education Initiative; the use of new technology, like remotely operated vehicles; and opportunities for collaboration. The roles of NOAA and Environment Canada scientific support coordinators were discussed as well as public outreach activities carried out by university-sponsored vessels. Partnership opportunities with Chicago's Shedd Aquarium, the Great Lakes Maritime Heritage Center, and a unique research program being carried out on the sea cadet vessel, *Pride of Michigan,* were also highlighted during these workshops.

7.4.3 Partnerships and Outreach

The 2005 workshop made a concerted effort to draw support from the Great Lakes Captain's Association (GLCA) by coordinating the workshop with the GLCA Industry Days program. This initiative, as well as the high-quality training opportunities available at GLMA, has increased workshop participation. Future plans call for a workshop session to be held in conjunction with the 2006 IAGLR conference in Windsor, Ontario, as well as another joint GLASS/GLCA event in Traverse City. Outreach activities include production of a Great Lakes science vessel brochure and a professional-quality display that can be used at conferences to raise awareness about science ship coordination efforts. This display was produced in cooperation with GLERL and first used at the 2005 IAGLR Conference. The web site continues to attract public attention, with an average of more than 350 hits per month and over 7,000 hits in the past 18 months.

7.4.4 Recommendations

The Council recommends to the International Joint Commission that:

- **The Commission maintain its support and funding for science vessel coordination workshops sponsored by the Council of Great Lakes Research Managers to improve communication regarding vessels, and facilitate their coordination and use.**
- **The Parties significantly increase their investment in Great Lakes research, scientific technology, and research vessel fleet modernization to support the goals of the Agreement.**

7.5 Council Membership for 2003-2005

Canadian Members

Dr. Harvey Shear
(Canadian Co-chair)
Regional Science Advisor
Environment Canada

Dr. Robert C. Andrews
Department of Civil Engineering
University of Toronto

Dr. Alex T. Bielak
Director, Science Liaison Branch
National Water Research Institute
Environment Canada

Mr. Daniel Bondy
Manager, Environmental &
Occupational Toxicology Division
Environmental Health Sciences Bureau
Environmental Health Centre
Health Canada

Dr. Jan J.H. Ciborowski
Department of Biological Sciences
Great Lakes Institute for Environmental Research
University of Windsor

Mr. Dale Henry
Director
Drinking Water
Wastewater and Watershed Standards
Ontario Ministry of Environment

Dr. Saad Y. Jasim
Chief Executive Officer
Walkerton Clean Water Centre

Ms. Jacinthe Leclerc
Director
Environmental Conservation Branch
St. Lawrence Centre
Environment Canada

Mr. Luis G. Leigh
Director
Environmental Economics Branch
Economic and Regulatory Analysis Directorate
Environment Canada

Ms. Cheryl Lewis
Manager, Aquatic Research and Development Section
Applied Research and Development Branch
Ontario Ministry of Natural Resources

Dr. William J. Meades
Director, Forest Ecology
Canadian Forest Service
Natural Resources Canada
Great Lakes Forestry Centre

U.S. Members

Dr. Stephen B. Brandt
(U.S. Co-chair)
Director
Great Lakes Environmental Research Laboratory
National Oceanic and Atmospheric Administration

Dr. Leon M. Carl
Center Director
Great Lakes Science Center
U.S. Department of Interior
U.S. Geological Survey

Dr. Steven M. Colman
Director
Large Lakes Observatory
Drinking Water Management Division
University of Minnesota, Duluth

Dr. Joseph DePinto
Senior Scientist
Limno-Tech, Inc.

Dr. Chris DeRosa
Director, Division of Toxicology
CDC/Agency for Toxic Substances and Disease Registry

Mr. Paul Horvatin
Program Manager
U.S. Environmental Protection Agency
Great Lakes National Program Office

Dr. Janet R. Keough
U.S. Environmental Protection Agency
National Health and Environmental Effects Research Laboratory
Midcontinent Ecology Division

Mr. Jan Miller
Environmental Engineer
U.S. Army Corps of Engineers
Great Lakes and Ohio River Division

Dr. Edward L. Mills
Director/Professor
Department of Natural Resources
Cornell Biological Field Station

Mr. James R. Nicholas
Michigan District Chief
Water Resources Division
U.S. Geological Survey

Dr. Jeffrey M. Reutter
Director, Ohio Sea Grant College Program
The Ohio State University
Research Center

Binational Members

Dr. Patricia Chow Fraser
Department of Biology
McMaster University
Past President, International Association for Great Lakes Research

Dr. Charles C. Krueger
Science Director
Great Lakes Fishery Commission

Former Members

Dr. Thomas C. Johnson
Director/Professor
Large Lakes Observatory
University of Minnesota

Dr. David Blakey
Acting Director, Environmental Health Science
Environmental Contaminants Bureau
Environmental Health Centre
Health Canada

Secretary

Mr. Mark J. Burrows
International Joint Commission
Great Lakes Regional Office

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Chapter Eight

GREAT LAKES WATER QUALITY BOARD

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Chapter Eight

GREAT LAKES WATER QUALITY BOARD

8.1 Overview

The Board spent most of its time and effort during 2003-2005 on advice on review of the Agreement (Chapter One) and Annex 2 activities (Chapter Three). Board members served in a liaison capacity to the Science Advisory Board's (SAB) urbanization (Chapter Four) and human-health initiatives (Chapter Five). In addition to the urbanization issue, the Board received special briefings from the U.S. Environmental Protection Agency and the Ontario Ministry of the Environment on stormwater management, sewage blending, and combined-sewer overflows. The infrastructure for wastewater collection and treatment in urban areas is old and needs upgrading, at the same time that urban sprawl is causing more hardened surfaces and increased stormwater runoff, thereby resulting in stormwater overflows and bypasses. So-called "event monitoring" during wet weather conditions is often not conducted. Consequently, it is difficult to evaluate the impacts of such practices on water quality, sensitive beaches, and fish and wildlife habitats. The Board plans to further address urban infrastructure for wastewater management and stormwater runoff in selected Great Lakes urban centres during 2005-2007 in cooperation with the SAB and the International Air Quality Advisory Board.

The Board remains concerned about the aquatic invasive species problem in the Great Lakes, but has not conducted substantive work on this issue since completing its 2001 report, *Alien Invasive Species and Biological Pollution of the Great Lakes Eco-structure*. That report focused on preventing further invasive species introductions from the ballast-water pathway. The Board recognizes the importance of preventing invasive species introductions to the Great Lakes from all pathways, and will address this issue in 2005-2007.

8.2 Great Lakes Water Quality Board Membership 2003-2005

Canadian Members

Mr. Michael Goffin (Canadian Co-Chair)
Acting Regional Director General
Environment Canada, Ontario Region

Mr. Jim Smith
Assistant Deputy Minister/Chief Drinking Water Inspector
Drinking Water Management Division
Ontario Ministry of Environment

Dr. John Carey
Executive Director
National Water Research Institute

Mr. Alec Denys
Director, Great Lakes Branch
Ontario Ministry of Natural Resources

Mr. Charles Lalonde
Director, Resource Management
Ontario Ministry of Agriculture and Food

Dr. Jean Painchaud
Direction du suivi de l'état de l'environnement
Ministre de l'Environnement

Mr. Adel Shalaby
Regional Director
Healthy Environments and Consumer Safety Branch
Health Canada

Mr. Peter Thompson
Regional Director, Policy
Central and Arctic Region
Department of Fisheries and Oceans

Mr. J. Craig Mather
Aurora, Ontario

Mr. Paul Glover
Director General, Safe Environments Program
Healthy Environments and Consumer Safety Branch
Health Canada

U. S. Members

Mr. Gary V. Gulezian, (U.S. Co-Chair)
Director
U.S. Environmental Protection Agency, Great Lakes National Program Office

Ms. Lori Boughton
Chief
Office of Great Lakes
Pennsylvania Department of Environmental Protection

Mr. Gerald F. Mikol
Regional Director
New York Department of Environmental Conservation Region 9

Ms. Suzanne Hanson, Regional Manager
Minnesota Pollution Control Agency NE Region

Mr. Joseph P. Koncelik
Director
Ohio Environmental Protection Agency

Mr. Todd Ambs
Administrator-Division of Water
Wisconsin Department of Natural Resources

Marcia Willhite
Chief, Bureau of Water
Illinois Environmental Protection Agency

Mr. Thomas W. Easterly
Commissioner
Indiana Department of Environmental Management

Mr. Ken DeBeausseart
Director, Office of the Great Lakes
Michigan Department of Environmental Quality

Mr. Bruce I. Knight
Chief
Natural Resources Conservation Service
U.S. Department of Agriculture

David A. Ullrich
Great Lakes Cities Initiatives
Northeast Midwest Institute

Secretary

John E. Gannon
Great Lakes Regional Office
International Joint Commission

Former Members
David de Launay
Ministry of Natural Resources

John Mills
Environment Canada

Pradeep Khare
Environment Canada

Joel Weiner
Health Canada

Thomas Skinner
U.S. Environmental Protection Agency Region 5

Christopher Jones
Ohio Environmental Protection Agency

Lori Kaplan
Indiana Department of Environmental Management

Douglas A. Barnes
Ontario Ministry of Environment

APPENDIX

LIST OF ACRONYMS

ADCP – Acoustic Doppler Current Profiler

AIS – alien invasive species

AOC – Area of Concern

ATSDR – Agency for Toxic Substances and Disease Registry

AUV – autonomous underwater vehicle

BASS – Bioaccumulation and Aquatic System Simulator

BBDR – biologically based dose response

BDE – brominated diphenyl ether

BEC – Binational Executive Committee

BFR – brominated fire retardant

BMP – Best Management Practice

BPA – bisphenol A

BTBPE – bis(2,4,6-tribromophenoxy)ethane

BUI – beneficial use impairment

CAFO – concentrated animal feeding operation

CALFED – California-Federal

CDC – Centers for Disease Control and Prevention

CEC – Commission for Environmental Cooperation

CEPA – Canadian Environmental Protection Act

CFU – colony-forming unit

CHAD – Consolidated Human Activity Database

CODAR – coastal radar

CSFII – Continuing Survey of Food Intakes by Individuals

CSO – combined sewer overflow

CUSIS – Canada-United States Interuniversity Seminar

DBP – butylbenzylphthalate

DDE – dichlorodiphenyldichloroethylene

DDT – dichlorodiphenyltrichloroethane

DEHP – diethylhexylphthalate

DNA – deoxyribonucleic acid

ECPI – European Council for Plasticisers and Intermediates

EEA – European Environmental Agency

ENGO – environmental non-government organization

EOHSI – Environmental and Occupational Health Sciences Institute

EPA – Environmental Protection Agency

FDA – Food and Drug Administration

FIA – flow injection analyzer

GAWSER – Guelph All Weather Sequential Events Runoff model

GBMM – Grid-Based Mercury Model

GC-MS – gas chromatography / mass spectrometry

GEOSS – Global Earth Observing System of Systems

GIS – geographic information system

GLASS – Great Lakes Association of Science Ships

GLCA – Great Lakes Captain's Association

GLERL – Great Lakes Environmental Research Laboratory

GLFC – Great Lakes Fishery Commission

GLMA – Great Lakes Maritime Academy

GLNPO – Great Lakes National Program Office

GLOS – Great Lakes Observing System

GLU – Great Lakes United

GOOS – Global Ocean Observation System

HAB – harmful algal bloom

HABSOS – Harmful Algal Blooms Observing System

HACCP – Hazard Analysis and Critical Control Point

HBCD – hexabromocyclodecane

HCB – hexachlorobenzene

HEV – hepatitis E virus

HHCB – 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamethyl-cyclopenta-gamma-2-dibenzopyran

HYSPLIT – Hybrid Single Particle Langrangian Integrated Trajectory

IADN – Integrated Atmospheric Deposition Network

IAGLR – International Association for Great Lakes Research

IAQAB – International Air Quality Advisory Board

IBEM – Individual Based Exposure Modeling

IC – impervious cover

IEM-2M – Indirect Exposure Model, Version 2

IJC – International Joint Commission

IQ – intelligence quotient

kg-bw/day – kilogram of body weight per day

LaMP – Lakewide Management Plan

LC-MS – liquid chromatography / mass spectrometry

LEMN – Lake Erie Millennium Network

LID – low-impact development

LOEL – lowest observed effects level

MDN – Mercury Deposition Network

MeHg – Methylmercury

MENTOR – Modeling Environment for Total Risk

MEP – monoethylphthalate

METAALICUS – Mercury Experiment to Assess Atmospheric Loading in Canada and the United States

METS – Metabolic Equivalent of Tasks

MOE – Ministry of the Environment

NAFTA – North American Free Trade Agreement

NDBC – National Data Buoy Center

NERL – National Exposure Research Laboratory

N-EtFOSE – N-ethyl perfluorooctane sulfonamidoethanol

N-MeFOSE – N-methyl perfluorooctane sulfonamidoethanol

NGO – non-government organization

NHANES – National Health and Nutrition Examination Survey

NHEXAS – National Human Exposure Assessment Survey

NOAA – National Oceanic and Atmospheric Administration

NOEC – no observed effect concentration

NP – nonylphenol

NPEO – nonylphenol ethoxylate

NRC – National Research Council

OP – octylphenol

OPEO – octylphenol ethoxylate

PBDE – polybrominated diphenyl ether

PBEM – Population Based Exposure Modeling

PBTK – Physiologically Based Toxicokinetic

PCB – Polychlorinated biphenyl

PCDD – polychlorinated dibenzo-para-dioxin

PCDF – polychlorinated dibenzo-furan

PCR – polymerase chain reaction

PFC – perfluorinated chemicals

PFOA – perfluorooctanoic acid

PFOS – perfluorooctane sulfonate

PLUARG – Pollution from Land Use Activities Reference Group

POPs – persistent organic pollutants

PBTs – persistent bioaccumulative and toxic chemicals

ppb – part per billion (µg/kg, ng/g, µg/L, or ng/mL)

PPCPs – pharmaceuticals and personal care products

ppm – part per million (mg/kg, mg/L)

PTFE – polytetrafluoroethylene

QSAR – quantitative structure-activity relationship

RAB – Great Lakes Research Advisory Board

RAP – Remedial Action Plan

REA – relaxed eddy accumulation

RfD – Reference Dose

RFP – Request for Proposal

RGM – Reactive gaseous mercury

ROV – remotely operated vehicle

RSC – Royal Society of Canada

SAB – Great Lakes Science Advisory Board

SAR – Synthetic Aperture Radar

SHEDS-4M – Stochastic Human Exposure and Dose Simulation for Multiple co-occurring contaminants and Multimedia, Multipathway, Multiroute exposures

SOLEC – State of the Lakes Ecosystem Conference

SUNY – State University of New York

TBBPA – tetrabromo bisphenol A

TDS – Total Diet Study

TMDL – total maximum daily load

UNECE – United Nations Economic Commission for Europe

UNEP – United Nations Environment Programme

U.S. – United States

USGS – United States Geological Survey

UV – ultra violet

WASP – Water Quality Analysis Simulation Program

WCS – Watershed Characterization System

WhAEM2000 – Wellhead Analytic Element Model

WQB – Great Lakes Water Quality Board

WWTP – wastewater treatment plant